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Pollution loadings of urban storm runoff.

Ronald L. Droste
University of Windsor

POLLUTION LOADINGS OF URBAN STORM RUNOFF

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Ronald L. Droste

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ABSTRACT

Larger urban populations, increased use of waters and stricter laws on pollution entering waters have enlarged the importance of urban stormwater runoff pollution. A brief history of urban stormwater runoff pollution is presented. Studies on rainfall and dustfall pollution are reviewed.

Stormwater runoff from an homogeneous residential area in Windsor, Ontario was sampled and measured for twenty-five storms over a one year period of time for the following: bio-chemical oxygen demand, total and fecal coliform, nitrates, nitrites, ammonia, ortho-phosphates, sulfates, chlorides, total suspended solids, volatile suspended solids, grease and oil, total alkalinity, phenolphthalein alkalinity, total hardness, calcium hardness, pH, specific conductance, colour, turbidity, temperature and discharge. Analyses and sampling method are reported. Rainfall data was gathered. Some storms had to have hydrographs synthesized. The method for generating hydrographs is discussed and the results are presented.

Seasonal and annual qualities and loadings are reported. Variation of qualities and loadings with time and rainfall intensities are investigated. The loads of constituents contained in incremental volumes of runoff were researched and regression equations describing this load-volume relation were generated. Regression analysis between and among the constituents for quality relationships were performed. The best models found were among the inorganic constituents, turbidity and total suspended solids and total and fecal coliforms (for summer only).

The average concentration of runoff constituents for a residential-light commercial area is predicted. Comparison of runoff loads to sanitary sewage loads is made. There is a discussion of the pollution potential of the constituents. It is concluded that treatment of urban stormwater runoff should be implemented before tertiary treatment of sanitary sewage. Recommendations for further research are made.

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GLOSSARY

a	constant
A	cross-sectional area
$A_{(I)}$	area
AES	Atmospheric Environment Service
APWA	American Public Works Association
ASCE	American Society of Civil Engineers
b	constant
BOD	biochemical oxygen demand
C_i	runoff coefficient by RRL method
C_{im}	mean RRL runoff coefficient
COD	chemical oxygen demand
C_R	rational runoff coefficient
CR	chart reading
F-value	ratio of regression mean square to residual mean square
i	amount of runoff
I	integer > 0
LOG	logarithm referred to base e
M	integer > 0
n	Manning's roughness factor
N	integer > 0; nitrogen
P	phosphorous
$P_{(I)}$	virtual runoff
P_V	per cent of total runoff volume
Q	discharge
$Q_{(I)}$	discharge
r	rainfall
R_C	Pearson product-moment correlation coefficient
RRL	Road Research Laboratory
R-square	square of the multiple correlation coefficient
S	stage; storage
SS	suspended solids
T	time
Te	time of entry
Tc	time of concentration
TS	total solids
TSS	total suspended solids
v	average velocity
VSS	volatile suspended solids
WPCF	Water Pollution Control Federation
Y	mass emission rate per cm. of runoff
z_1	time since start of rainfall
z_2	antecedent amount of rainfall
z_3	amount of last previous rainfall of 0.10 in. or more

z_4 time (hr.) since last previous rainfall of 0.10 in. or more

z_5 average intensity of last previous rainfall

[ ] concentration

Chapter I

INTRODUCTION

Investigation into the nature of combined sewer overflows has prompted research into the nature of urban stormwater runoff itself. Urban stormwater runoff has been found to be an unsuitable diluent for sanitary sewage, yet it is not as heavily loaded as sanitary sewage. Increased pollutional loads on waters, and current legislation to limit discharge of pollutants has enlarged the importance of stormwater runoff. Economics of treatment for the variable runoff phenomena are high and other uses for it are being sought.

1.1 History of the Problem

In earlier times when North American cities were constructed the sewers built were combined. Stormwater runoff was considered to be relatively clean. Overflows from the combined sewers were not considered very harmful because the greater volume of runoff diluted the sanitary sewage. Kohlhaas [6] writes that about year 1900, separate sewers were advocated to eliminate innocuous overflows of the combined systems. However, a very high percentage of sewer systems in urban areas are still of the combined type; about one-half of the U.S. urban population is served by combined sewers [3],[54].

The quality of overflows in the combined systems began to be researched in the 1950's. These studies led to examination of stormwater runoff itself. Palmer in 1949 [15] found biochemical oxygen demand (BOD)* and total solids of up to 234 p.p.m. and 914 p.p.m. respectively in a Detroit catch basin. But he concluded that the costs of a separate sewer system in a densely populated area were prohibitive and that stormwater treatment at individual outlets or a common outlet was better. Another study on the nature of stormwater runoff found total suspended solids (TSS) over 2000 mg/ℓ and BOD's up to 100 mg/ℓ [31]. Bacteriological quality was likewise found to be poor, maximum values reported by Burm and Vaughan [32] for an Ann Arbor storm drain were 34,000,000 total coliforms/100 ml and 750,000 fecal coliforms/100 ml. Lead, phenols and pesticides were measured in stormwater runoff. In the above studies and others, (in Chap. VII results of studies are reported comprehensively) it was concluded that stormwater runoff is not a suitable diluent for sanitary sewage. The fact that quality of runoff is worse in the earlier stages of runoff or the so-called first flush phenomena was established by many.

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*Abbreviations used in this work are in the Glossary.

Pollutional loadings of runoff were also researched by some. Suspended solids loads in runoff were usually found to be much higher than those of untreated sanitary sewage on a kg/hectare (ha)/year basis, BOD loadings were around 7 per cent of sanitary loads in Weibel et al.'s study [29]. Studies indicated urban runoff to be a significant contributor of pollutants to streams and lakes. Urban runoff has been estimated to contribute near 4.5 per cent and 5.8 per cent of nitrogen and phosphorous content respectively to U.S. stream waters [64]. Weibel [28] estimated urban runoff to contribute about 4 per cent of the phosphate load to Lake Erie. Sylvester and Anderson [34] concluded that untreated stormwater should not be admitted to Green Lake in Seattle if the lake is to recover.

In view of the pollution loading of stormwater runoff and that of combined sewer overflows, some cities feel the need to at least separate existing combined systems. In Washington, D.C. their schedule calls for one-third separation of sewers by the year 2000 at an estimated cost of $44,000/ha ($18,000/acre) [2]. Chicago costs are similar [2]. Overflows from combined sewers were to be treated in New York City beginning in 1967 [5]. Söderlund and Lehtinen [35] from their study in Stockholm, note that stormwater runoff contributes as much pollution to waters (except for phosphorous) as combined sewer overflows.

1.2 Statement of the Problem

Most of the studies to date concern themselves with only a few constituents of urban runoff. A great portion of their emphasis has been on the qualitative as opposed to the quantitative characteristics of runoff. Veissman [1] comments in 1968, "No attempt to relate rainfall or runoff to urban water quality constituent concentration in a generally useful manner has been reported as far as the author is aware." The American Public Works Association (APWA) [54] expressed similar feelings in 1969.

Empirical or mathematical models of constituent loadings in the urban runoff process are needed to make possible reasonable decisions on separation of sewers, treatment of overflows or treatment of the stormwater itself. Bryan [41] concludes that treatment of stormwater runoff may be the next logical step before implementation of tertiary treatment for sanitary sewage. A Tulsa group [26] asserted similar reasoning. All constituents of urban runoff need to be identified and quantified to determine what treatment is most feasible and which uses (e.g. industrial) can be made of runoff. Variation of runoff loadings with time and other pertinent factors still need to be described to estimate effects on streams and lakes.

Urban population in Canada in 1971 was 76.3 per cent of Canada's total population [65]. The urban population has been growing and will probably continue to grow. This will add to the importance of urban stormwater runoff water pollution in future years.

1.3 Objectives of This Study

This study attempts to answer some of the questions raised in the preceding section as follows:

1) Stormwater runoff from a homogeneous residential area is to be examined for these constituents: pH, colour, turbidity, specific conductance, TSS, volatile suspended solids (VSS), phenolphthalein alkalinity, total alkalinity, calcium hardness, total hardness, chlorides, sulfates, orthophosphates, ammonia, nitrates, nitrites, BOD, total coliforms, fecal coliforms, grease and oil and temperature.

2) The above constituents will be related to the amount of rainfall and runoff to determine loadings.

3) Seasonal and yearly loadings and qualities will be calculated; their variation as a storm progresses will be noted.

4) Regression analysis will be applied to the constituents and discharge to determine relationships among them.

5) Needed capacity to subject stormwater loadings to treatment will be examined.

6) A comparison of loadings from this study to those of another study of a residential area in the same city but of different socio-economic status will be made.

7) All possible data pertaining to rainfall, runoff and constituents of the storms analyzed will be gathered and reported to allow accurate use of this data in future studies and comparisons.

Chapter II

THE AREA CHOSEN FOR THE STUDY

2.1 The City of Windsor, Ontario

Windsor is a heavily industrialized city, whose population is about 200,000, located in the southernmost point on the border between Ontario, Canada and Michigan, U.S.A.. It lies on the Detroit River across from Detroit. The area of the city of Windsor in 1971 was 10,900 ha (46.2 mi^2) with population density of 16.50 persons/ha (4,397 persons/mi^2) [56]. The automobile industry and associated counterparts make up most of the industry.

The climate [66] is temperate with a growing season averaging 210 days, 165 of which are frost-free. The mean annual temperature is 8.3°C (47°F), with a winter mean of -3.3°C (26°F) and a summer mean of 21.1°C (70°F). Air temperature extremes vary from -31.6°C (-25°F) to 37.8°C (100°F).

2.2 The Drainage Area Chosen for Study

Figure 2-1 is a 1972 aerial view of the residential area chosen for study on the east end of

Fig. 2-1. An Aerial View of the Experimental Area.

town. Figure 2-2 is a map of the area and surrounding locale.. This area was chosen because it is a homogeneous area sewered by a separate system. The area comprising 11.94 ha (29.5 acres) is within 1.61 kilometers (km) (1.0 mi.) of a large auto assembly plant. The population of the area is about 590 [67] which equals a density of 49 persons/ha (20 persons/acre). The area is predominantly wartime single family frame housing built during 1945-1950 (City of Windsor information). This housing was a government relief project and the area tends to be populated by lower middle class people. Singh [7] in 1971 did a study on runoff in a newly built middle to upper middle class district about 3.2 km (2 mi.) from this area.

Paved streets are mostly asphalt with very little concrete; some of the asphalt is well worn to the point where the streets are dirt streets. Refer to Fig. 2-3 for views of the experimental area. There are no paved alleys although there is a light layer of rock in most of them. The drainage area is bordered by one small park and a large grassy test driving grounds, other residential area and a heavily trafficked four lane street. Very little drainage from the heavily trafficked street reaches the sewer system that was sampled. Trees, gardens, shrubs and usually small backyards are established in the neighbourhood. There

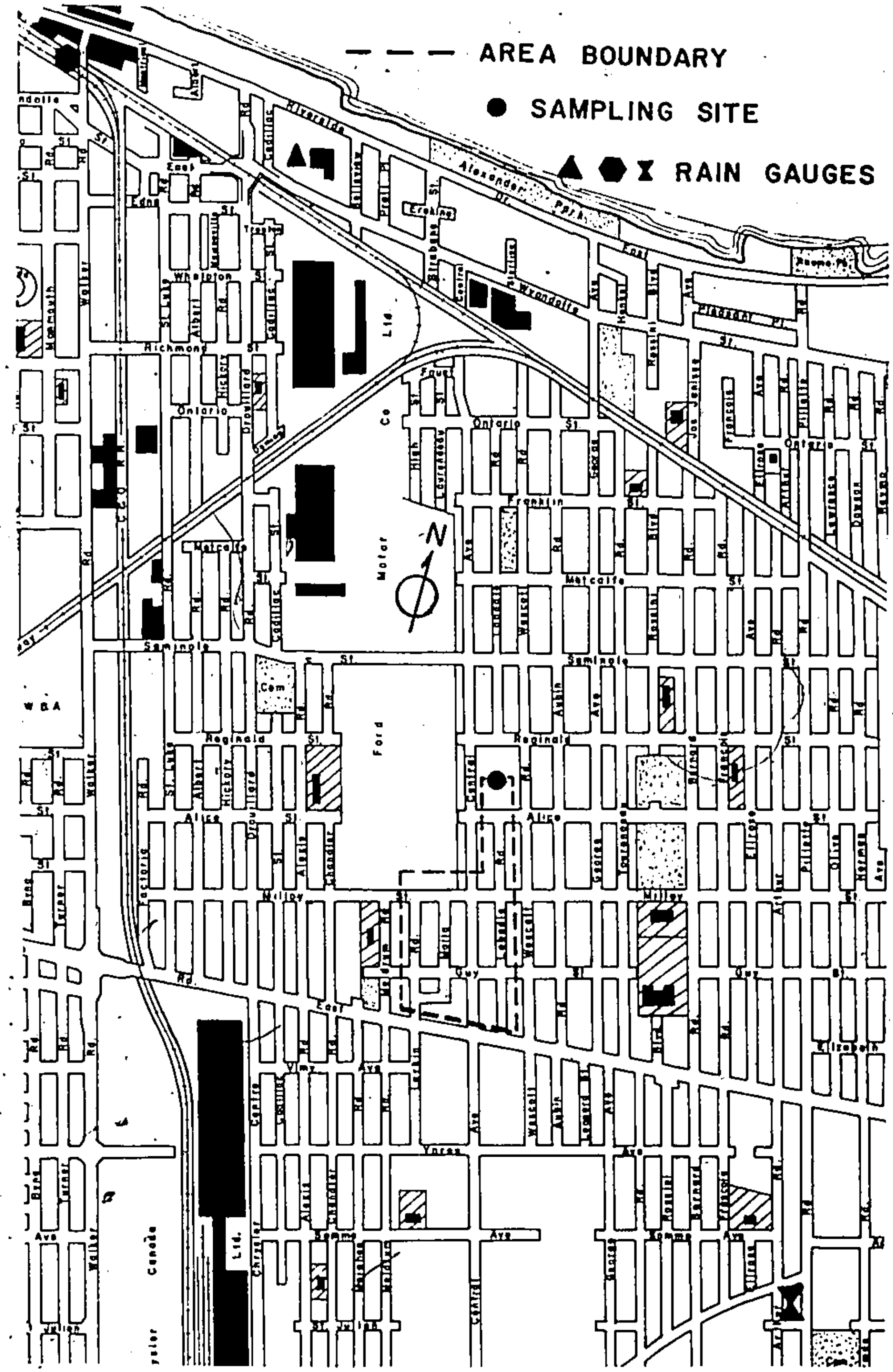

FIG. 2-2. THE IMMEDIATE VICINITY OF THE STUDY AREA.

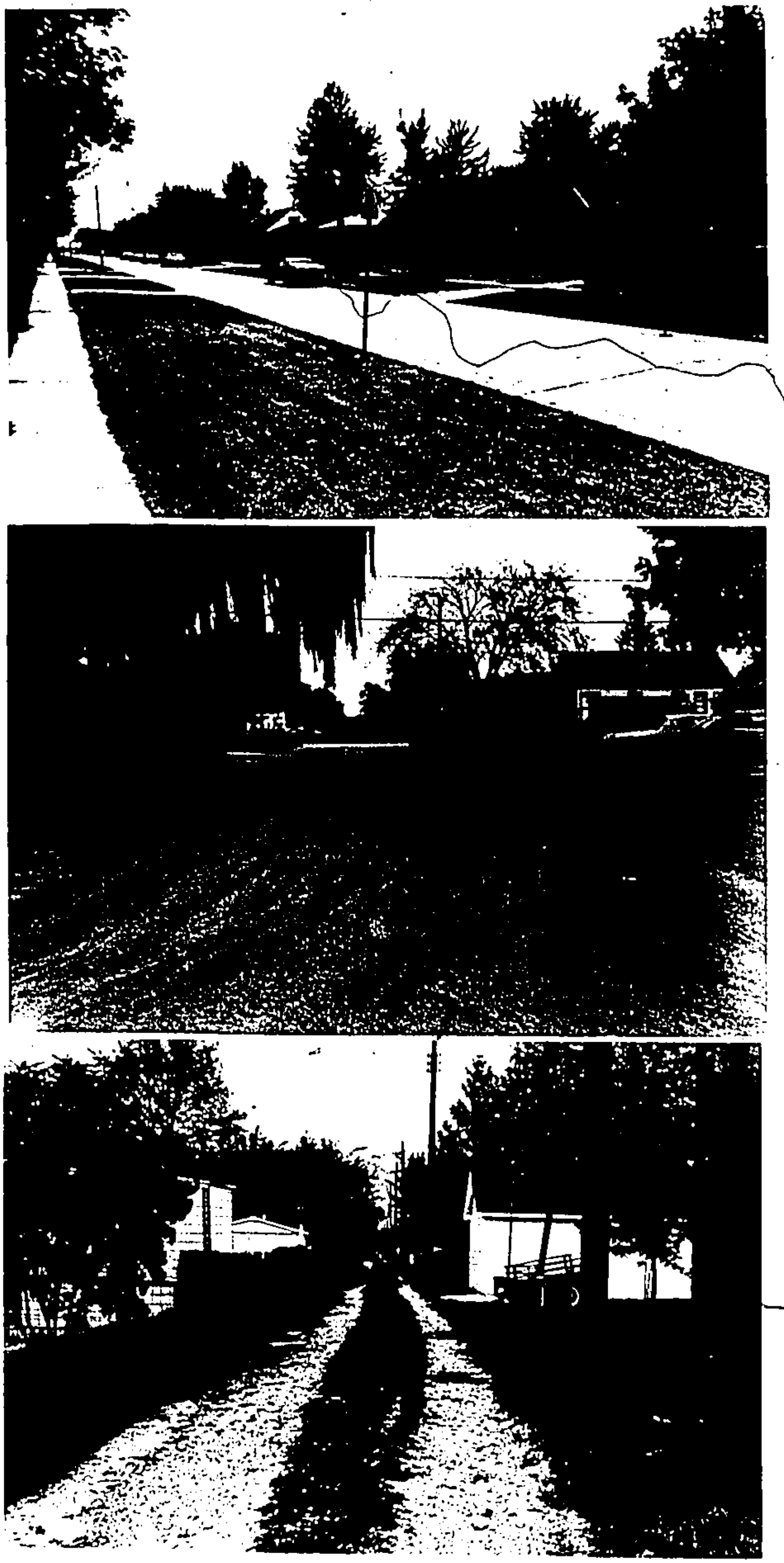

Fig. 2-3. Views of the Experimental Area.

are no bus routes that directly drain into the sewer of interest, but Central Avenue is a bus route.

The area is flat with 20 cm. (8 in.) to 23 cm. (9 in.) of clay top soil which is above hard, brown rather impervious silty clay soil [8].

2.3 The Sewer System

The sewer system is a separate sewer system constructed in about 1935. There were no foul sewage odours in the storm drain throughout the course of sampling, although a typical musty odour was present. A sketch of the storm drain is shown in Fig. 2-4. The sewers begin at Tecumseh Road, however, the Central Avenue storm sewer is not connected into the sewer that reaches the collection point. All these separate storm sewers eventually enter the Detroit River untreated. The sewer sizes range from 30.5 cm. (12 in.) diameter at the beginning to 53.3 cm. (21 in.) in the final stretch where the sample collection point was located. The slope of the sewer varies between 0.25% and 0.30%.

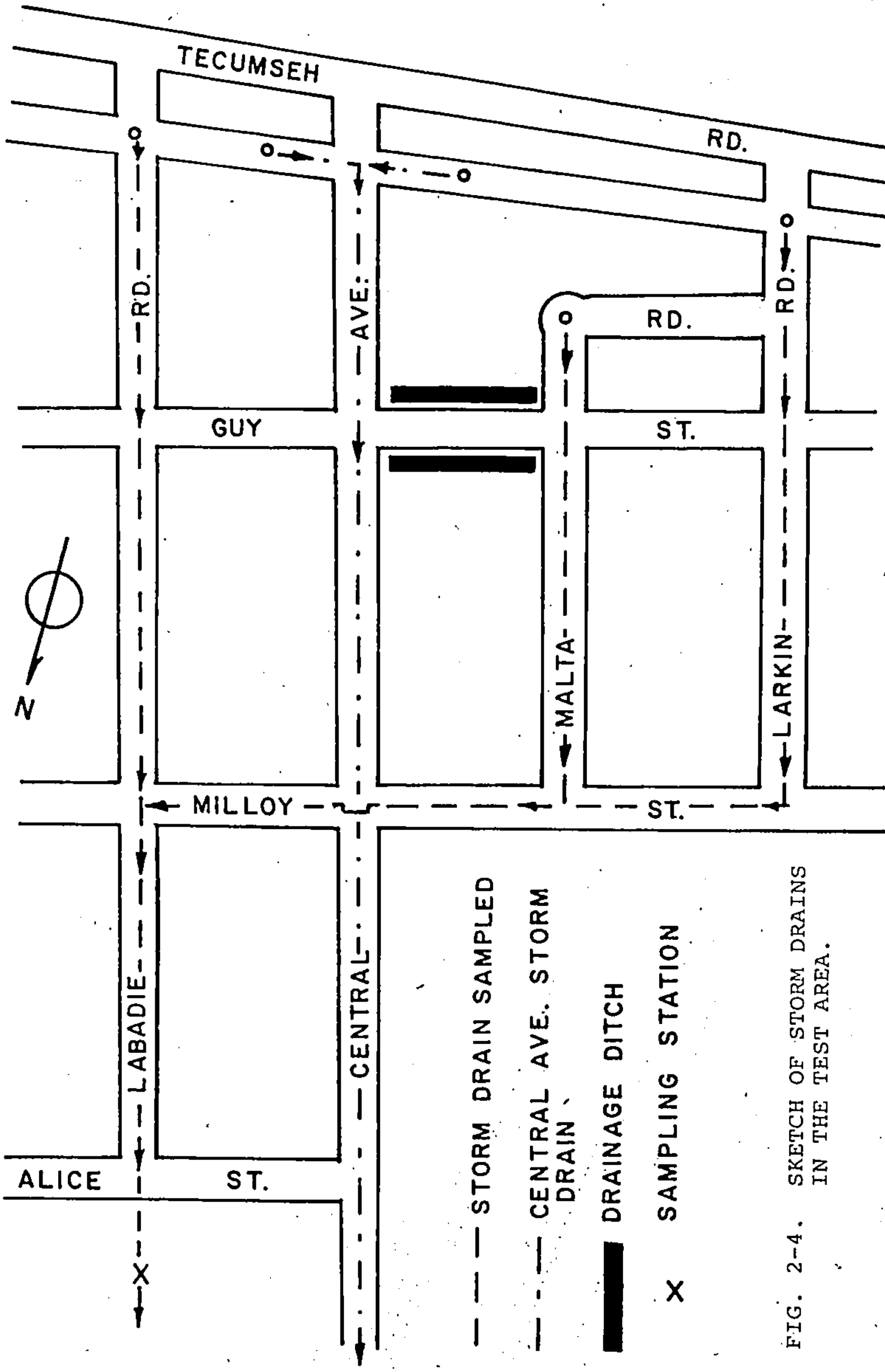

FIG. 2-4. SKETCH OF STORM DRAINS IN THE TEST AREA.

Chapter III

DUSTFALL AND RAINFALL

To gain perspective and further qualification of stormwater runoff pollution, literature on dustfall and rainfall pollution is examined.

3.1 Dustfall Pollution

Dustfall contributes significant amounts of various substances to stormwater runoff. Dustfall suspended solids (SS) at a Cincinnati test site [24] measured 567 kg./ha. (506 lb./acre) for one year, the VSS rate of fall was 193 kg./ha/ (172 lb./acre) for the same period of time. From a survey of the literature Johnson et al. [52] in the 1950's and 1960's found average dustfall loadings to range from 648 kg./ha./yr. (577 lb./acre/yr.) for Tacoma to 2,680 kg./ha./yr. (2,380 lb./acre/yr.) for New York City. Ranges of dustfall constituents found for Seattle in Johnson et al.'s study are listed in Table 3-1. The higher values of all constituents except phosphates occurred in heavy industrial areas, while phosphates were generally highest at residential area sampling stations.

Average dustfall in Windsor for December 1967 through November 1968 was between 1,425 kg./ha./yr. (1,271 lb./acre/yr.) and 1,715 kg./ha./yr. (1,574 lb./acre/yr.) [53]. The APWA in Chicago [54] concluded that the dust and dirt portion of street litter (of course not all of that dust and dirt is due to dustfall) has the most significant water pollution potential.

3.2 Rainwater Pollution

Weibel *et al.* [29],[42] performed analyses of rainfall in Cincinnati with the results shown in Table 3-2. The values of these parameters are not seen to be too high except for the nutrient values of nitrogen (N) and phosphorous (P), which both exceed Sawyer's index [45] of 0.3 mg/ℓ inorganic N and 0.03 mg/ℓ PO_4 for nuisance algal blooms.[1,2] Weibel *et al.* further sampled rainfall near Coshocton, Ohio, a rural area. Values found there were not significantly different from those in Table 3-2 except for hydrolyzable PO_4

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[1] In a more recent evaluation of the role of PO_4 in lake fertilization, Sawyer continues the suggestion of 0.03 mg/ℓ inorganic PO_4 as the limiting value to suppress undesirable algal growths. He also concludes phosphorous to be generally the key element in lake fertilization [46].

[2] Vollenweider [47] has also made a very extensive review of the literature on fertilization of lakes with emphasis on N and P and agrees with Sawyer for both limits.

Table 3-1

Range of Loadings for Constituents in Dustfall in Seattle*
(After Johnson *et al.* [52])

Constituent**	Loading Range (kg./ha./yr.)***
Water insoluble dustfall	60 - 2280
Water soluble dustfall	36 - 1680
Water soluble calcium	2.4 - 312
Water soluble nitrates	0.36 - 19.2
Water soluble sulfates	24 - 720
Water soluble phosphates	0 - 7.2

*Study done in June, July, August of 1965.
**Water soluble lead and fluorides were also analyzed.
***Multiply by 0.893 for lb./acre/yr.

Table 3-2

Constituent Concentrations of Rainfall at Cincinnati
(After Weibel *et al.* [29])

Constituent	Storm Ranges	Storm Average
pH	3.9 - 6.10	4.8*
SS, mg/ℓ	0.5 - 58.0	13.0
VSS, mg/ℓ	0.5 - 12.0	3.8
COD, mg/ℓ	4.6 - 59.0	16.0
Total N, mg/ℓ	0.5 - 2.80	1.3
Inorganic N, mg/ℓ	0.12 - 2.30	0.69
Hydrolyzable PO_4, mg/ℓ	0.0 - 0.90	0.24
Organic Chlorine, μg/ℓ	0.08 - 0.41	0.28

*median value

which was 0.08 mg/ℓ [42]. Weibel [28] estimates that rainfall over Lake Erie contributes from 2 to 6.5 per cent of the total phosphorous input to the lake. Geldreich et al. [43] found coliform counts in rainfall to be usually less than one per 100 ml.

The average composition of total salts in rainfall is 11 mg/ℓ and consists mainly of Na^+, Ca^{++}, Mg^{++}, K^+, NH_4^+, Cl^-, $SO_4^=$, HCO_3^- and NO_3^- [48]. Ciaccio [48] further quotes information stating that rainfall contributes almost one-half of the dissolved solids load in streams of the U.S. for NO_3^-, $SO_4^=$, Cl^-, Ca^{++}, Mg^{++}, Na^{++} and K^+.

Junge [50] from a survey of ammonium and nitrate in U.S. rainwater reported a wide variation in their concentrations with areal and temporal distribution. The concentrations of either were generally less near the coastlines. Soil of an area rather than industrial or fertilizer application were concluded to be the major source of fixed nitrogen. Matheson [51] studied inorganic N reaching the ground in Hamilton, Ontario and found that 61 per cent of total inorganic N fall, fell on days with some precipitation, which were only 25 per cent of all days. Median values of nitrogen fall on days with precipitation were in the range of 0.008 mg./ha. (2.0 mg./mi.^{2}) to 0.01 mg./ha. (3.0 mg./mi.^{2}).

Rainfall - Dustfall Constituent Analysis in Windsor

The University of Windsor Geography Department has performed analyses of rainwater in the City of Windsor collected over a one month period for various constituents. However, the sample collection containers are not covered and are subject to dust contamination. Table 3-3 lists results of these analyses. This study was begun in Feb., 1971 and continues at this time.

3.3 Precipitation Measurement for This Study

The Department of Geography at the University of Windsor has a system of precipitation gauges located throughout the City of Windsor and Essex County. These gauges record all forms of precipitation to the nearest 0.025 cm. (0.01 in.) of water. The hourly accumulation of precipitation is reported. The locations of the gauges most often used in this study are marked on Fig. 2-2. The distances from the centroidal point of the experimental area of the three primary gauges used, E-4, E-11, and E-13, were 3.12 km. (1.94 mi.), 2.51 km. (1.56 mi.) and 1.51 km. (0.94 mi.) respectively. These gauges were not all functioning for all storms. In some cases discussed later on in this section, other city gauges had to be used. The general location of all Geography Department gauges is shown in Fig. 3-1. The distances from the experimental area centroid of

Table 3-3

Rainfall-Dustfall Analysis for Windsor

(After Sanderson [44])

Time Period	Specific Conductance milli-mhos/cm	Nitrates, mg/l as N	Sulfates, mg/l	Orthophosphates, mg/l	Total Alkalinity, mg/l as $CaCO_3$	TSS, mg/l	VSS, mg/l	pH
January	81.3	0.73	23.1	0.03	27.5	123	97	6.74
February	95.7	1.34	15.7	0.04	10.5	60	22	6.31
March	50.0	1.26	15.5	0.01	7.0	65	36	6.95
April	55.2	0.83	12.6	0.03	10.4	97	63	6.73
May	55.6	1.00	19.1	1.26	7.7	41	13	6.93
June	49.8	1.18	17.9	1.42	5.6	44	14	7.02
July	51.6	1.05	19.1	0.52	8.4	48	22	6.93
August	44.4	0.96	16.7	0.77	18.5	119	89	6.53
September	43.8	0.50	20.4	1.01	16.8	126	95	6.60
October	56.8	1.08	21.1	0.47	19.0	133	103	6.18
November	46.5	0.20	17.5	0.41	25.0	201	131	6.55
December	37.6	0.43	21.4	0.12	24.5	131	84	7.20
Winter	75.6	1.11	18.1	0.03	15.0	83	52	6.67
Spring	53.5	1.60	16.5	0.90	7.9	61	30	6.89
Summer	46.6	0.83	18.7	0.77	14.6	98	69	6.69
Fall	46.9	0.57	20.0	0.33	22.8	155	106	6.64
Annual	55.6	0.88	18.3	0.51	15.1	99	58	6.72
Winter, 1973	78.3	1.06	13.9	0.05	11.5	53	34	6.93
Spring, '73	58.5	1.76	15.7	0.53	9.9	59	19	6.97
Summer, '72-'73	50.5	1.18	14.7	0.97	10.5	52	33	6.80
Fall, '72	36.2	0.90	15.9	0.03	8.3	81	71	6.75
Sept. '72-Aug. '73	55.9	1.23	15.1	0.40	10.1	61	39	6.86

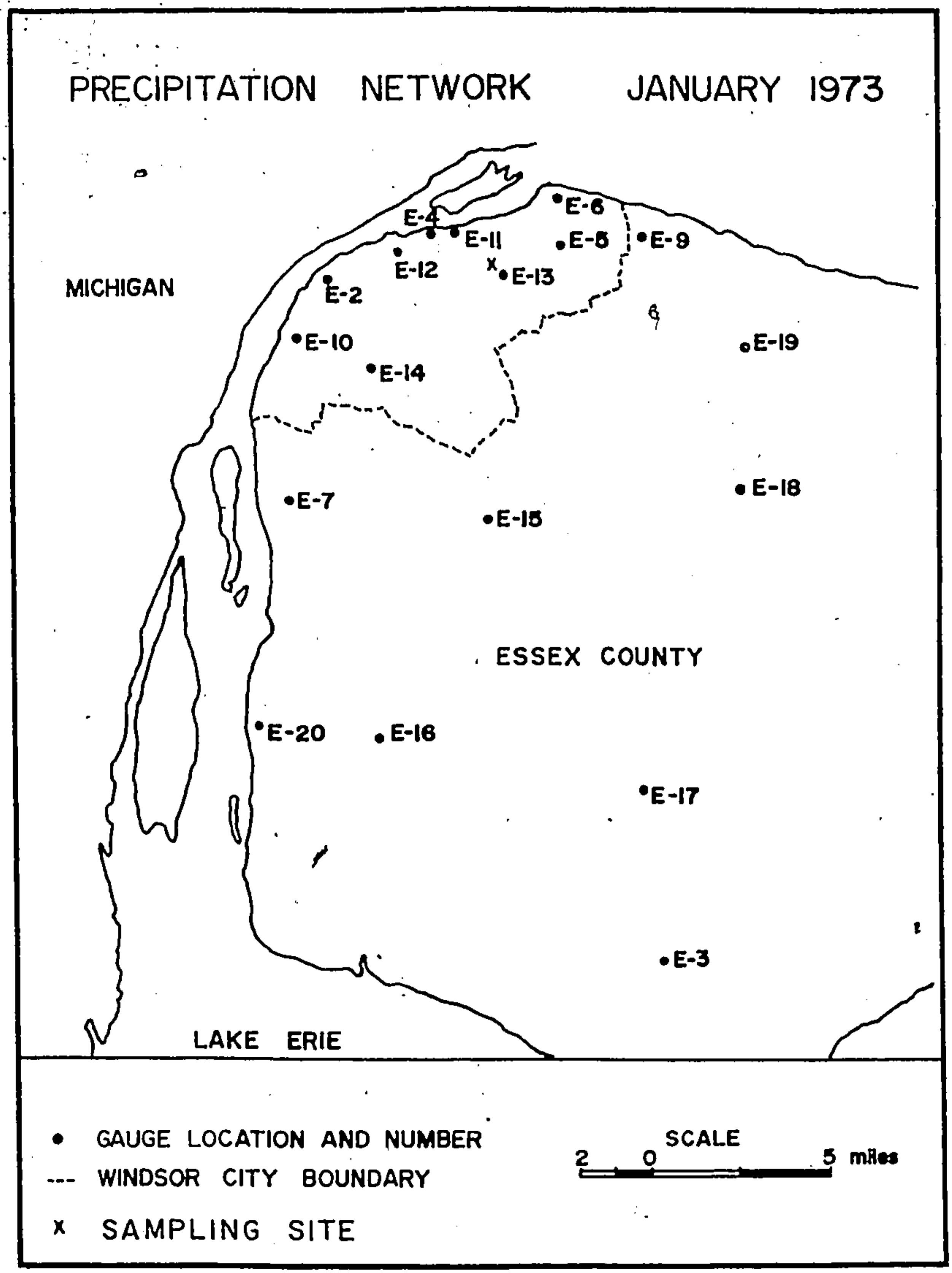

FIG. 3-1. PRECIPITATION NETWORK IN WINDSOR.

other gauges used, E-2 and E-5 were 4.65 km. (4.13 mi.) and 4.64 km. (2.88 mi.) respectively.

The Windsor Airport, located 4.84 km. (3.0 mi.) southeast of the experimental area centroid also maintains an official precipitation gauge. They record six-hour precipitation accumulations and the beginning and end of heavy, moderate, and light precipitation periods, noting the form of the precipitation. To obtain hourly precipitation values from the airport, the six hour precipitation total was appropriately proportioned to the light, medium and heavy precipitation periods. The airport uses the following criteria for light, moderate and heavy rainfall periods respectively: 0.025 cm./10 min. (0.01 in./10 min.); 0.051 - 0.127 cm./10 min. (0.02 - 0.05 in./10 min.); and, equal to or greater than 0.152 cm./10 min. (0.06 in./10 min.).

3.3.1 Calculation of Hourly Rainfall for the Experimental Area

An attempt was made to use the Thiessen polygon method for computing rainfall over the area, but this method resulted in the study area being subject to only one gauge, E-13. Since individual well-placed gauges are subject to error, it was decided to use a weighted average of the gauges' readings. The weighted average depended on the inverses of the gauges' distances from the centroid of the experimental area for computing the hourly precipitation values. If gauge E-13 was functioning along with either or both of gauges E-4 or E-11, then E-13 and E-4 or E-11 or both were utilized. If gauge E-13 was not functioning, then gauges E-4 or E-11 or both along with gauges E-2 and E-5 were utilized. There were three exceptions to the preceding: for the storm of Nov. 10-11, 1972 only gauges E-9 and E-10 could be used; on Nov. 25-26, 1972 and Dec. 11-12, 1972 only gauge E-13 had available data. For the storm of No. 10-11 an average of the readings for gauges E-9 and E-10 was used. Table 3-4 lists the dates of the storms sampled, their total amount of precipitation, the gauges used to determine the precipitation and other data of interest later.

The airport data was used as a check against the Geography Department records primarily for total per storm values. If a discrepancy of 50 per cent or greater existed when comparing total precipitation for a storm from the Geography Department records and the airport records, this storm was not used in computing the runoff coefficient discussed in Section 4.2. Three of the storms did not meet this criterion, while two storms were within 40 per cent agreement and the remaining storms had a discrepancy of 25 per cent

Table 3-4

Dates and Precipitation Data of Storms Sampled

Storm No.	Date	Amount of Precipitation per Storm (cm)	E-gauges Used to Determine Precipitation	Preceding Time Period With Less Than .076 cm Precipitation
1	September 17-18, 1972	1.43	4,11,13	4.6 days
2	September 26, 1972	1.31	4,11,13	20 hours
3	October 21, 1972	0.94	4,11,13	5.7 days
4	October 22-23, 1972	4.29	4,13	3 hours
5	November 10-11, 1972	0.29	9,10	2.6 days
6	November 25-26, 1972	0.86	13	3 days
7	December 12-13, 1972	2.49	13	2.3 days
8	January 3-4, 1973	1.96	4,13	3.6 days
9	January 23-24, 1973	0.23	4,13	3 hours
10	February 1, 1973	0.28	4,13	4.0 days
11	March 10-11, 1973	2.41	2,4,5,11	7 hours
12	March 16-17, 1973	3.24	2,4,5,11	2.1 days
13	March 29, 1973	1.31	2,4,5,11	4.0 days
14	March 31, 1973	0.49	2,4,5,11	1.8 days
15	April 9, 1973	0.88	4,5,11	5.9 days
16	April 16, 1973	0.17	4,5,11	6.8 days
17	May 7-8, 1973	0.40	4,11,13	5.1 days
18	May 8, 1973	0.49	4,11,13	3 hours
19	May 27, 1973	1.07	4,11,13	4 days
20	June 6, 1973	0.47	4,11,13	1 day
21	June 26, 1973	2.43	4,11,13	2.7 days
22	July 10, 1973	0.23	4,5,11	7.4 days
23	July 20, 1973	1.30	4,5,11	10.1 days
24	July 26, 1973	2.10	4,5,11	5.5 days
25	July 31 - Aug. 1, 1973	1.73	4,11,13	2.9 days

or less. It is realized that storms can be local but the above criterion is a safety factor.

In Appendix A are graphed the calculated values of hourly rainfall intensity for the individual storms. Appendix B has other precipitation information pertaining to the sampled storms. Precipitation was primarily snowfall on Jan. 23-24, 1973 and the storms of Nov. 25-26, 1972 and Mar. 16-17, 1973 contained significant amounts of snowfall.

3.3.2. Time Smoothing of Hourly Rainfall Intensities

It must be pointed out that the method of using a weighted average of two or more rain gauges to compute hourly rainfall intensities does somewhat smooth time variations in rainfall intensities in the calculation. The storm of July 26 provides the only example corrected for this. Gauges E-4, E-11 and E-5 were used to compute hourly rainfall intensities. Their readings and the weighted calculated average for the hours of rainfall are shown in Table 3-5.

Table 3-5

Hourly Rainfall Intensities (cm.)* for Storm of July 26/73

HOUR		9	10
GAUGE	E-4	1.70	0.00
	E-5	0.33	1.98
	E-11	0.13	1.91
Weighted Average		0.69	1.35

*multiply by 0.396 for in.

In this case, by observation at the sample site, the rainfall lasted only a few minutes less than one hour. Therefore, a total of 2.04 cm. of rain was assigned to hour number ten. This form of time smoothing undoubtedly occurred in precipitation intensity calculations for other storms.

3.4 Annual and Seasonal Rainfall in Windsor

The total precipitation per month for the City of Windsor from September, 1972 through August, 1973 were calculated by averaging total precipitation from all city gauges that functioned throughout the month in a given month. These data and 30 year monthly precipitation values are shown in Table 3-6. The monthly amounts of precipitation in the storms sampled are also listed in Table 3-6. Average seasonal and annual precipitation is shown in Table 3-7. The seasons are defined as follows: winter is January through March; spring is April through June; summer is July through September; and, fall is October through December. Annual rainfall ranges from 45.7 cm. (18 in.) to 99.1 cm. (39 in.) [66].

Table 3-6

Average Monthly Precipitation* and Average Monthly Precipitation in 1972-1973 for Windsor
(Average Monthly Precipitation after AES [10])

	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
Precipitation (cm.)+	6.07	6.32	6.20	6.35	5.54	5.21	6.63	8.10	8.31	8.36	8.28	8.23
Snowfall (cm.)	0.00	Trace	10.2	23.1	26.4	23.1	17.0	4.32	Trace	0.00	0.00	0.00
Sept. 1972 - Aug. 1973	Sept. '72	Oct.	Nov.	Dec.	Jan. '73	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
Precipitation From Sept. '72 - Aug. '73 (cm.)	8.03	6.60	7.44	7.01	3.86	1.91	11.43	2.84	7.24	14.94	10.21	4.78
Amount of Rainfall Sampled (cm.)	2.74	4.29**	1.15	2.49	2.19	0.28	7.45	1.05	1.96	2.90	5.36	0.00

*30 yr. average for 1941-1970.
**Does not include storm of Oct. 21, 1972.
+Multiply by 0.393 for in.

Table 3-7

Thirty Year Seasonal and Annual Precipitation in Windsor*
(After AES [10])

Season	Winter	Spring	Summer	Fall	Annual
Precipitation (cm.)	17.38	24.77	22.58	18.87	83.60

*30 yr. average for 1941-1970.

Chapter IV

RUNOFF

4.1 Recorded Hydrographs

4.1.1 Stage Level in the Sewer

The stage level in the sewer was measured by an Arkon Water Level Recording Instrument, Model 63. The instrument was connected by a continuously air fed small bore impulse pipe to a diptube immersed in the flow. (An in situ view of the flow measuring and sampling instrument is shown in Fig. 5-1). The actual stage level in the sewer was measured at different levels and noted on the recorder chart. A regression analysis [11] of chart stage level reading on actual stage level was then performed to obtain the calibration curve shown in Fig. 4-1. The equation of the line and other statistics are noted in that figure.

4.1.2 Discharge - Stage Relation

Velocity of flow in the sewer at various stages was measured by dropping sodium fluorescein dye dissolved in water into the flow at the manhole immediately above the sampling site manhole and timing its arrival at the site. The distance between the

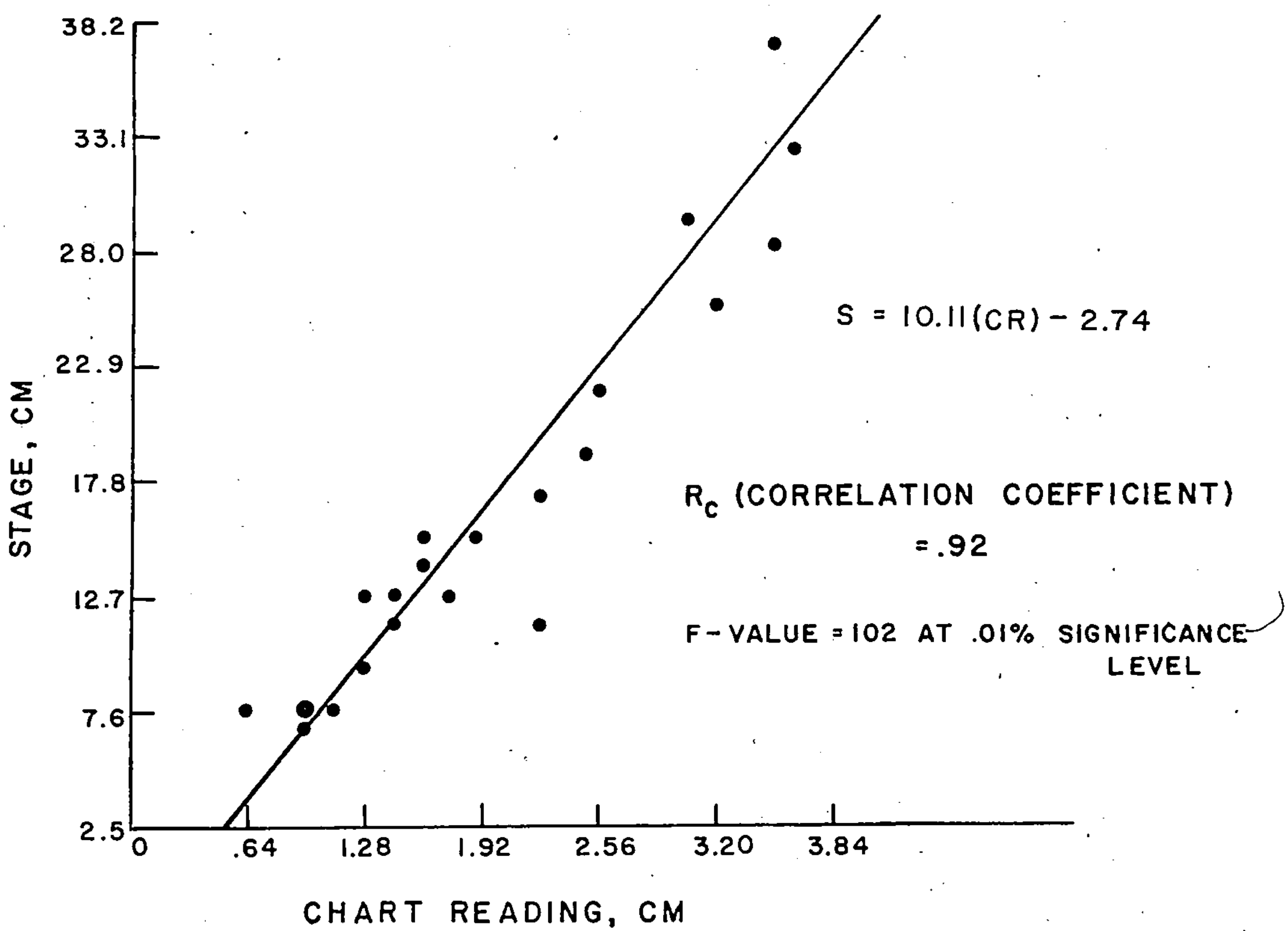

FIG. 4-1. CALIBRATION CURVE TO DETERMINE STAGE IN THE SEWER.

manholes was accurately measured for calculating these velocities. Also, velocities at four different stages were measured with a Current Meter, type C1, No. 18802 by A. Ott to check the above determined velocities. Agreement was excellent between the meter and dye methods. Knowing the stage, diameter of the sewer and velocity of flow, discharge was calculated for all measurements using the relationship

$$Q = Av$$

where Q is discharge,
A is cross-sectional area of flow, and
v is average velocity of flow.

Chow [12] demonstrates that stage and discharge should follow a Log-Log relationship for uniform flow (up to a certain stage that depends on variation of the roughness factor, n, except near full pipe flow). The data was so plotted in Fig. 4-2 for the measured depths, or stages which were up to 25.4 cm. (10 in.) deep in a 53.84 cm. (21 in.) diameter pipe.

The relationship determined for stages to 25.4 cm. deep was

$$\text{Log } Q = -7.43 + 3.66 \text{ Log } S$$

where Q is discharge in ℓ/sec
S is stage in cm.

$$\text{or } Q = 0.00059\ S^{3.66} \qquad (4.1)^*$$

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*Symbols and terms used in equations are defined in the glossary.

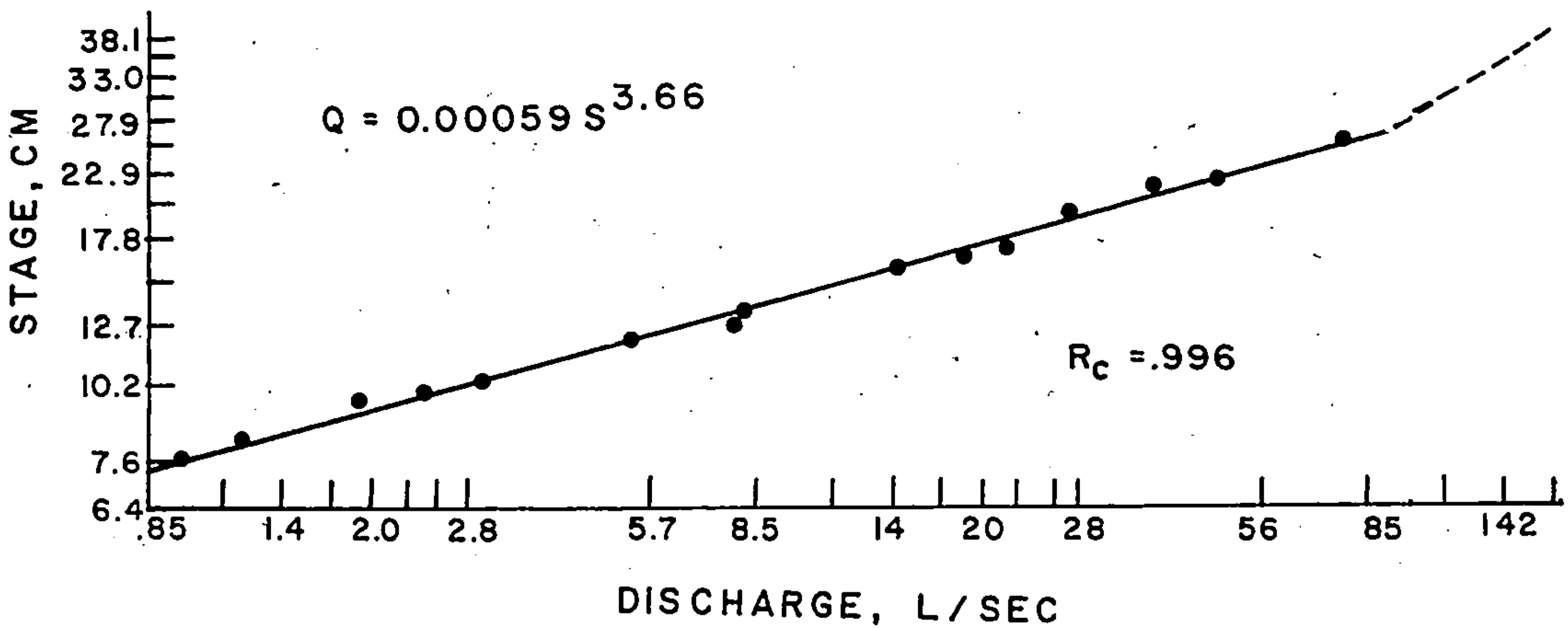
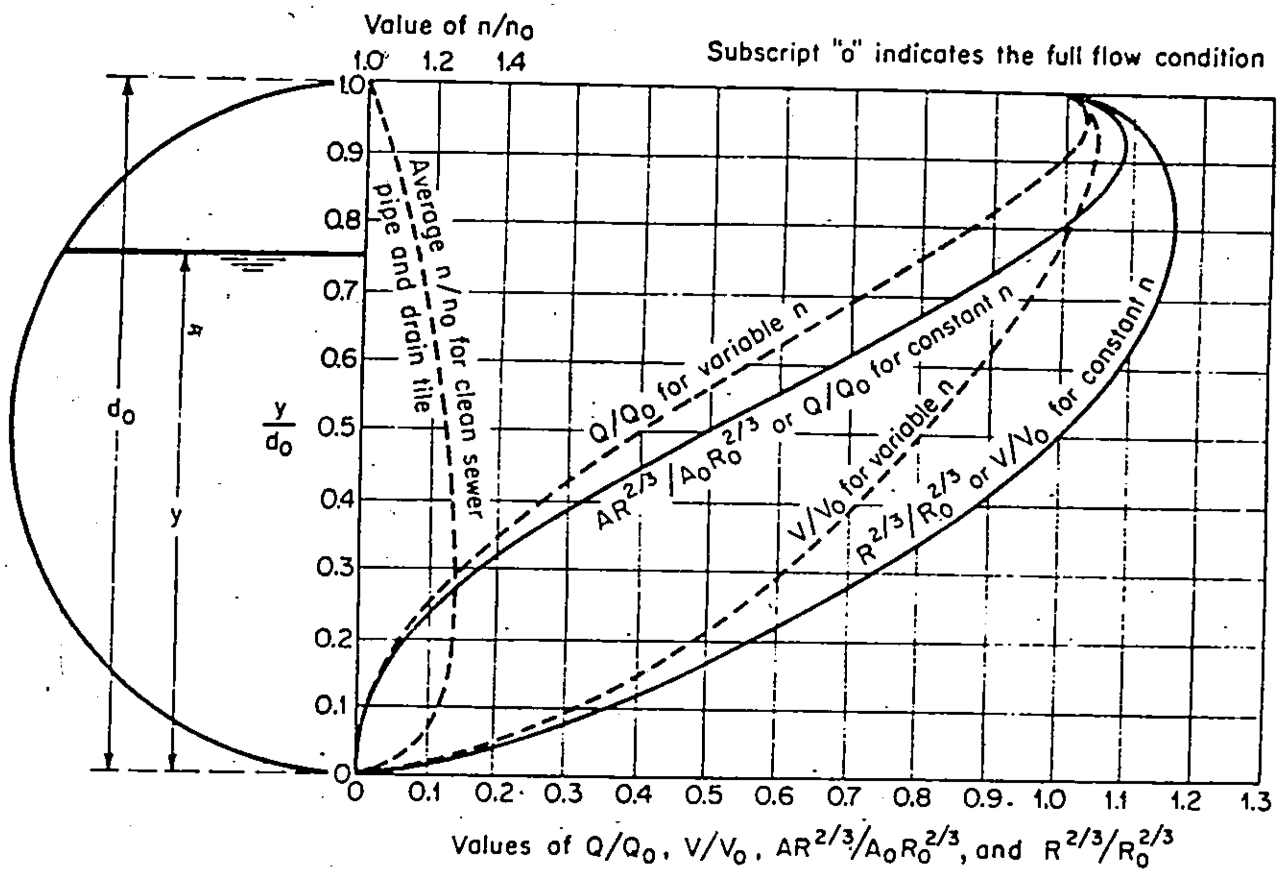


FIG. 4-2. STAGE-DISCHARGE RELATION FOR THE SEWER.

Since no velocity measurements were made at depths of flow greater than 25.4 cm. (10 in.) this part of the curve had to be constructed. The diameter of the circular sewer at the sampling point was 53.3 cm. (21.0 in.). When flowing more than half full, variation in the friction factor and its effects must be considered as discussed by Camp [13], Chow [12] and others [14]. Figure 4-3 was prepared by Camp. It relates discharge, stage and other factors for a varying friction factor in a circular sewer. From Fig. 4-3 for a varying friction factor the velocity of flow in a half-full circular sewer is approximately 0.8 of the full-flow velocity. As the ratio of stage to diameter rises from 0.5 to 0.9 the discharge rises from 0.4 to 1.0 in near linear fashion. Similarly, Fig. 4-4 was plotted for discharge and stage, constructing the portion below stage equal to 26.7 cm. (10.5 in.) (one-half the sewer diameter) and discharge equal to 0.4 full discharge using Eq. (4.1). The upper half of the curve was constructed in accordance with Fig. 4-3. These values were then transferred to Fig. 4-2 completing the stage-discharge relationship to a stage of 38 cm. (15 in.). In the storms sampled, the stage seldom rose above 26.7 cm. (10.5 in.) and never above 36.8 cm. (14.5 in.)



d – DIAMETER, y – DEPTH, n – MANNING'S ROUGHNESS COEFFICIENT
Q – DISCHARGE, A – AREA OF PIPE CROSS-SECTION, V – AVERAGE VELOCITY
R – HYDRAULIC RADIUS

Fig. 4-3. Flow Characteristics of a Circular Section (After Camp [13]).

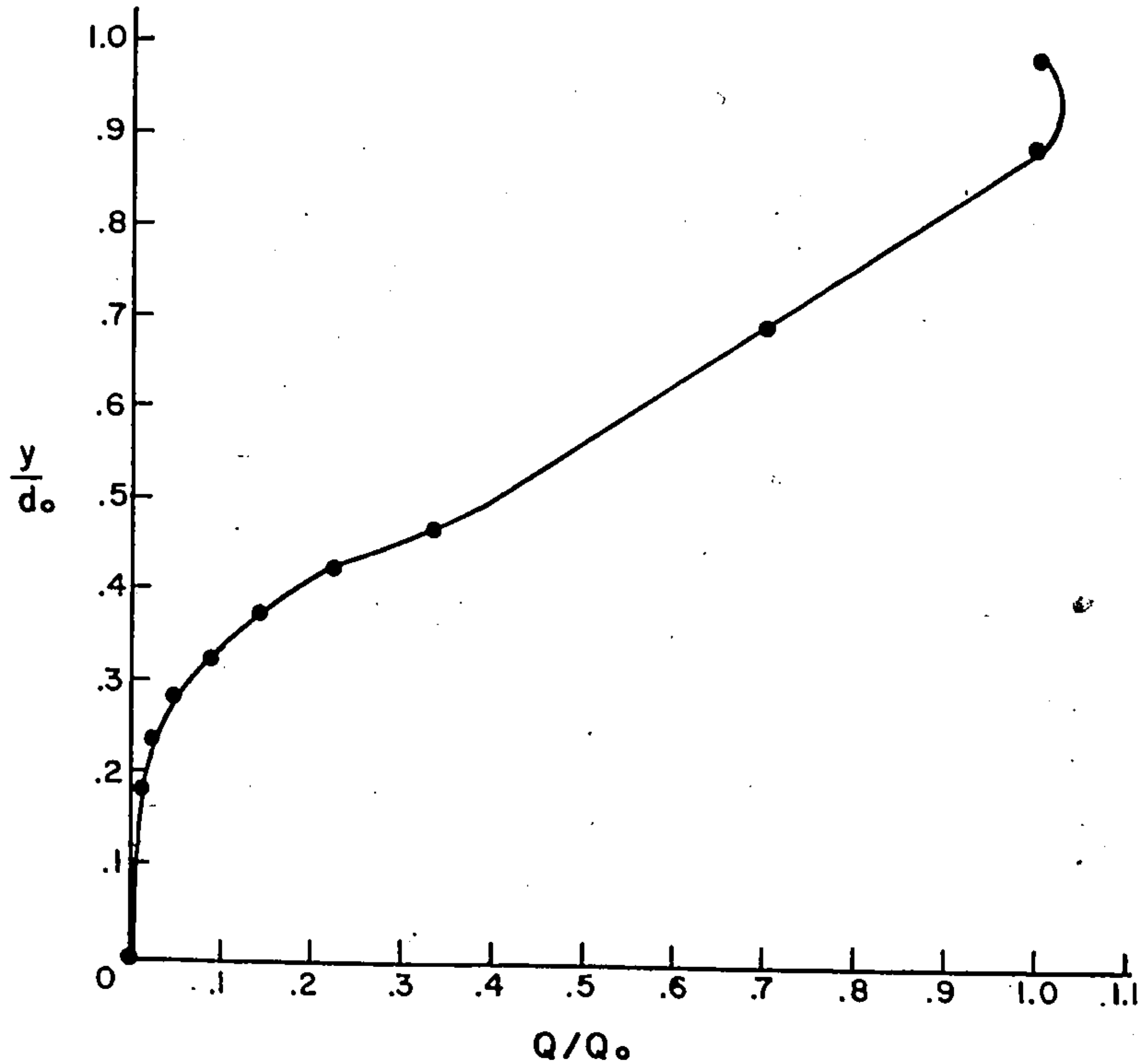


FIG. 4-4. FLOW CHARACTERISTICS OF THE SEWER IN THIS STUDY.

The flow level recorder did not always function. Moisture problems and debris in the sewer would hamper its operation. The hydrographs of the storms for which it functioned (listed in Table 4-1) are graphed as they naturally occurred in Appendix A.

4.2. The Runoff Coefficient

To generate hydrographs for the sampled storms not listed in Table 4-1 the British Road Research Laboratory (RRL) Method was chosen for reasons to be discussed later. The runoff coefficient (C_i) used in the above method is defined in Eq. (4.2).

$$C_i = \frac{\text{Total Volume of Runoff from Catchment Basin}}{\text{Total Effective Volume of Precipitation on Impervious Area of Catchment Basin}} \tag{4.2}$$

The total impervious area of the catchment basin includes paved streets, sidewalks, driveways, and houses connected to the storm drain and any other impervious areas connected to the storm drain.

The sewer plan and dye placed in street gutters were used to determine the contributing areas. The area of the paved streets and sidewalks was then calculated, estimating the effective impervious area of well worn pavement (refer to Fig. 2-3). The average number of driveways and their size was measured by visual survey of the area; this was also done for houses connected to the sewer system. The total impervious area of the catchment basin, being the sum of the above was 4.53 ha (11.20 acres).

For each storm with a recorded hydrograph, the area under the hydrograph was measured by planimeter to find the total volume of runoff from which the base dry weather flow was subtracted. This determined total volume of runoff for each storm with a recorded hydrograph.

Only University of Windsor Geography Department data was used in determining total precipitation for all storms. The total effective precipitation was taken as the total precipitation for a storm minus the surface wetting value of precipitation which was assumed to be 0.076 cm. (0.03 in.) of rainfall. Palmer's [15] studies in Detroit indicated that runoff did not occur until precipitation exceeded 0.076 cm./hr. (0.03 in./hr.). McKee [68] agrees with this wetting value. The American Society of Civil Engineers (ASCE) and Water Pollution Control Federation (WPCF) in their manual [14] give a surface wetting value of 0.127 cm. (0.05 in.) for impervious surfaces. In this study, examination of stage recordings showed that, in most cases, there was no runoff when total precipitation was 0.076 cm. (0.03 in.) or less. McKee [68] in Boston found significant runoff to be caused by 0.025 cm./hr. (0.01 in./hr.) rainfall intensity after surfaces had been well wetted.

4.2.1 Calculation of the Runoff Coefficient

Table 4-1 lists the average annual runoff coefficient (C_{im}) and the coefficients for the storms in which discharge was measured. The storms of Mar. 31, Apr. 16, and May 8 were not used to obtain the average yearly runoff coefficient because there were large discrepancies in Geography Department rainfall data and airport data (see section 3.3.1). For example, the runoff coefficient computed for Mar. 31 was 1.096 using Geography Department rainfall data; using airport data $C_i = 0.414$. The storm of May 7-8 was not included in determining C_{im} because rainfall intensity on this date was less than 0.076 cm./hr. (0.03 in./hr.) for more than half the duration of the storm, consequently a very low runoff coefficient was obtained.

The standard deviation of the nine runoff coefficients used for C_{im} was 0.266. The standard deviation of C_{im} was 0.089.

4.2.2 Comparison of the Mean Runoff Coefficient

No seasonal trends were observed in the runoff coefficients. Singh [7] who studied a nearby residential area in Windsor did observe considerable variation in the runoff coefficient seasonally, the winter runoff coefficient being especially high compared to other seasons. He calculated the rational runoff coefficient

C_R defined:

$$C_R = \frac{\text{Total Volume of Runoff from Catchment Basin}}{\text{Total Volume of Precipitation over Catchment Basin Area}} \tag{4.3}$$

His results are presented in Table 4-2. Only one storm in Singh's study was used to establish the winter runoff coefficient. The rational runoff coefficient (C_R) determined for this study was 0.171.

One of the many possible reasons for the difference in the winter runoff coefficients for these two studies was average winter temperatures. A check of airport records of monthly temperatures revealed that average temperature in January, February and March of 1971 (winter period of Singh's study) were -6.3°C (20.7°F), -2.6°C (27.3°F) and -0.1°C (31.9°F) respectively. For the same months of this study, average temperatures were -1.83°C (28.7°F), -4.2°C (24.4°F) and 5.7°C (42.3°F) respectively. Therefore, temperatures were higher in winter for this study and on the average a lower runoff coefficient would be expected. Also temperatures on the days before and during a storm would have major influence on the runoff coefficient for that storm as well as soil moisture content.

The ASCE and WPCF [14] report the range of coefficients, C_R, to be 0.30 to 0.50 for single family

Table 4-1

Runoff Coefficients**
for Storms with Recorded Hydrographs

Date	C_i
Sept. 17,18, 1972	0.336
Sept. 26, 1972	0.462
Feb. 1, 1973	0.208
Mar. 10-11, 1973	0.414
Mar. 16-17, 1973	0.758
Mar. 29, 1973	0.258
Mar. 31, 1973	1.096
Apr. 16, 1973	1.327
May 7-8, 1973	0.096
May 8, 1973	0.991
May 27, 1973	0.191
June 6, 1973	1.029
July 26, 1973	0.449
*Sept. 1972-Aug. 1973	0.452

*Does not include storms of Mar. 31, Apr. 16, May 7-8, and June 6, 1973.

**Calculated by the RRL Method.

Table 4-2

Singh's Seasonal Runoff Coefficients*
(after Singh [7])

Season	Runoff Coefficient
Winter	0.84
Spring	0.33
Summer	0.19
Fall	0.14
Annual	0.38

*Calculated by Rational Method.

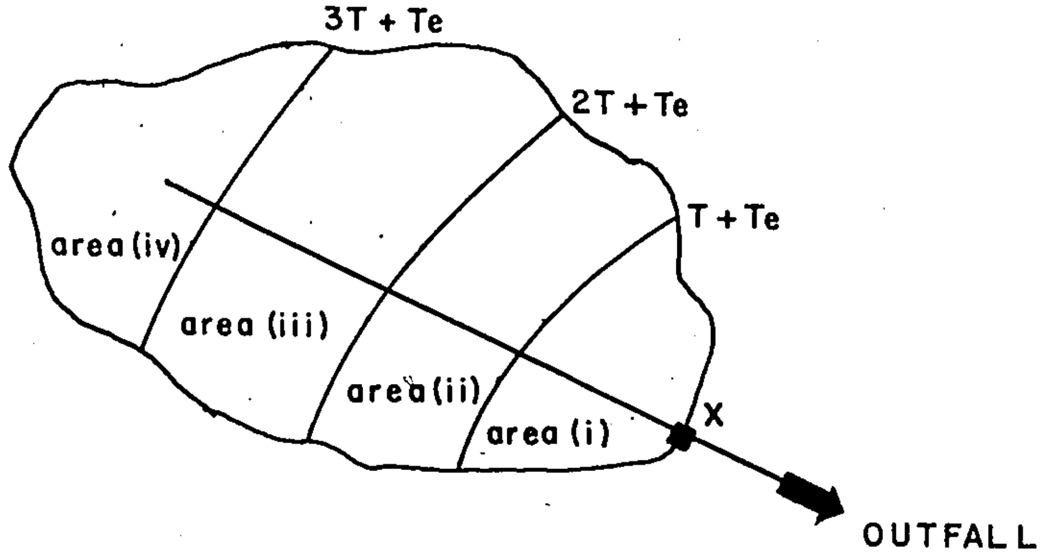
residential areas. Watkins [17] in describing the RRL Method asserts that C_i (Eq. 4.2) should be near 1.0. Terstriep and Stall [18] found C_{im} (mean RRL runoff coefficient) to be 0.84 and 0.90 for two different areas respectively. The runoff coefficient found in this study is about 50 per cent of runoff coefficients cited for either the RRL or rational method. But the study area was completely developed 25 years ago and is not comparable to more recent developments in drainage efficiency. A few portions of the area did not have a sufficient number of sewer inlets, there were numerous large depressions and other escapes for runoff to pervious areas. A greater portion of runoff than assumed could have entered the drainage ditches or the Central Avenue sewer (Fig. 2-4). The estimation of impervious area of the well worn paved streets could also have been too high. Regardless, the calculated runoff coefficient does accurately (within statistical limits) describe the proportion of rainfall passing through the experimental site in relation to the chosen impervious area.

4.3 Synthetic Hydrographs

The British designed Road Research Laboratory (RRL) Method for generating a synthetic hydrograph from a given rainfall input is described in detail in references [17], [18] and [19]. The method, which can be programmed for the computer, provides an uncomplicated, relatively accurate means of generating a continuous hydrograph. McKee [68] found it logical to assume that only runoff from impervious areas be considered for low intensity storms. Weibel [28] found that the ratio of total runoff to total precipitation over his study area was equal to the ratio of impervious area to total area of his study. Watkins [17] and Terstriep and Stall [18] note the success of the RRL method in application.

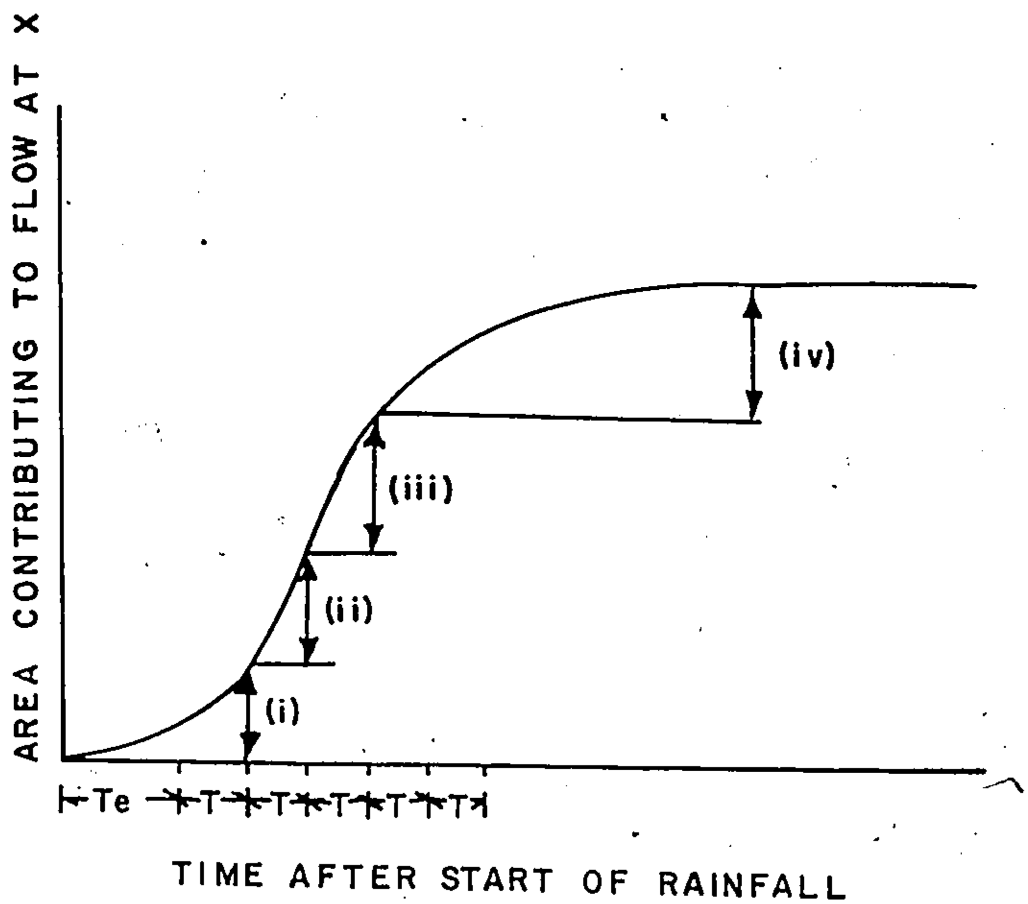
4.3.1 The RRL Method

The basic procedure for the RRL method is as follows: (i) The sewer system above the point in question is mapped out in terms of hydraulic characteristics - length, roughness, diameters, and slopes. (ii) The impervious areas (Fig. 4-5(a)) contributing to a length of sewer are calculated. Average times of surface flow to the inlet and inlet time are noted for each area. (iii) An area-time diagram (Fig. 4-5(b)) showing each increment of area contributing to the system in time T is then constructed from (i) and (ii). The time of flow along the sewer is calculated using full-bore velocities. Te is time of entry for area 1. The effective amount of rainfall, r, in time T is then applied to the whole impervious area and a virtual system inflow hydrograph is created. The virtual hydrograph at time Te + T·I (I is a positive integer) is found from the series below.



IMPERVIOUS AREAS MAP

FIG. 4-5(a).



AREA – TIME DIAGRAM

FIG. 4-5(b).

$$P_{(I)} = r_{(I)}A_1 + r_{(I-1)}A_2 + \cdot\cdot\cdot r_{(I-N)}A_{N-1}$$

where $P_{(I)}$ is the virtual runoff at time $T \cdot I + Te$
$r_{(m)}$ is the amount of rainfall during time interval $T_{(M)}$
$A_1, A_2 \ldots A_N$ are increments of impervious area for each increment T on the area-time diagram.

i.e. A_1 is contributing after time T + Te.

A_2 is contributing after time 2T + Te.

A_N is contributing after time NT + Te.

(v) The fifth step is to correct the virtual hydrograph for storage effects in the sewer. At any depth of flow in the sewer, water is stored due to that depth. Watkins [17] suggests two methods for obtaining a storage-discharge curve: (1) for a sewer to be designed, the proportional depth of flow is assumed to be the same throughout the system; (2) for existing systems the storage-discharge curve can be obtained by selecting storms in which no rain fell after the peak rate of runoff occurred. The recession portions of these hydrographs are superimposed, from which a mean curve is derived giving the storage-discharge relationship.

It is assumed that the volume of liquid stored at time T is S_1 and the volume stored at time 2T is S_2 and that the respective runoff quantities are Q_1 and Q_2. Referring to Figure 4-6,

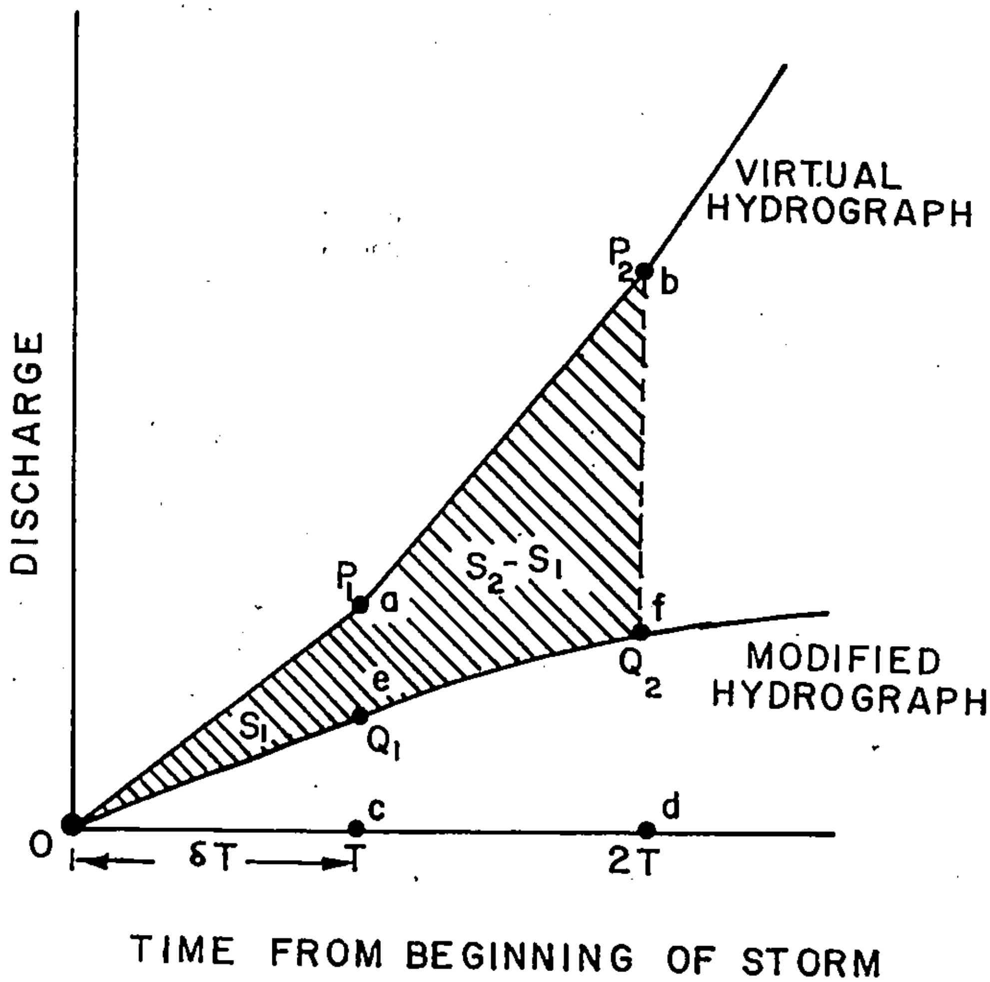


FIG. 4-6. MODIFICATION OF VIRTUAL HYDROGRAPH.

area Oac = area Oae + area Oec or

$$\frac{P_1 T}{2} = S_1 + \frac{Q_1 T}{2}$$

also, area abdc = area efdc + area abfe

or, $$\frac{(P_1 + P_2)}{2} T = \frac{(Q_1 + Q_2)}{2} T + (S_2 - S_1)$$

Knowing the inflow, one can compute Q and S.

4.3.2 Application of the RRL Method

From a city sewer plan of the area, the sewer lengths, diameters, and slopes were obtained. To determine the value of the Manning's roughness coefficient, n, the slope of the sewer between the site manhole and the manhole immediately above it was field measured. Using Fig. 4-4 the full flow velocity was found. Knowing that velocity and the slope, n was found to be 0.014 from the Manning formula. This value checks well with Chow's [12] for concrete channels and was used for all the sewers. Using the Manning formula, full flow velocities were calculated for all the different pipe sizes.

For paved areas the time of overland flow was assumed to vary from 5 to 10 minutes as the distance varies from 30.5 - 152.4 m. (100 - 500 ft.) [20]. In addition an inlet time of 5 minutes was assumed for all inlets (this 5 min. inlet time gave the best results). If an incremental area was found to contribute between a time of 10 and 15 min., the amount of its area contributing was assumed to increase linearly from 0 to 100 per cent between 10 and 15 min., respectively. This assumption was made for all areas. Time of concentration T_c, equalled the inlet time plus the time to flow down to the experimental site.

The total impervious area was divided into incremental areas contributing in 5 minute intervals between a time of 5 minutes and 35 minutes (see Fig.'s 4-5(a) and (b)). During the first 5 minutes no area was contributing because inlet time was 5 minutes. In the recorded hydrographs, the time of completion of the first rise in flow varied from 20 to 40 minutes.

The effective rainfall was obtained by ignoring the first 0.076 cm. (0.03 in.) of precipitation and multiplying the following precipitation by the runoff coefficient C_{im}. Each hourly total of precipitation was divided equally into 5 min. periods.

The storms of Mar. 31, May 8, June 6 and July 26 were used to determine the average recession curve for the storage-discharge relationship. Method (2) as proposed by Watkins was used. These storms had high rates of discharge after which no rainfall occurred. The experimenter was at the site when these storms occurred and the exact time at which rainfall ended was noted. Figure 4-7 shows the average recession curve obtained from the superimposed recession curves of the above noted storms. From the average curve, using a planimeter to measure area, the volumes of liquid remaining in the sewer at different discharges were calculated and plotted in Fig. 4-8. A line of best fit was drawn to the data in Fig. 4-8. The storage function (Fig. 4-8) was adjusted once to obtain better agreement between predicted and recorded values. The storage-discharge curve used (in Fig. 4-8) had a definite change of slope at about discharge of 3.54 ℓ/sec. (0.125 cfs.). The two equations governing storage in the two regimes of discharge are noted on Fig. 4-8. The computer program used for the RRL Method is listed in Appendix C. It is basically Warren's [19] with modifications.

4.3.3 Results of the RRL Method

Although the program was designed to print out discharge values for every 5 minutes, only average hourly values were used. There were two reasons for this: (1) rainfall data was only available on an hourly basis, which does not reflect variations in rainfall intensity during the hour and has the effect of time-smoothing the hydrograph curve; and, (2) only hourly discharge values were required for further use in this study. An example of (1) is the storm of Mar. 11, 1973. Its recorded hydrograph and the RRL

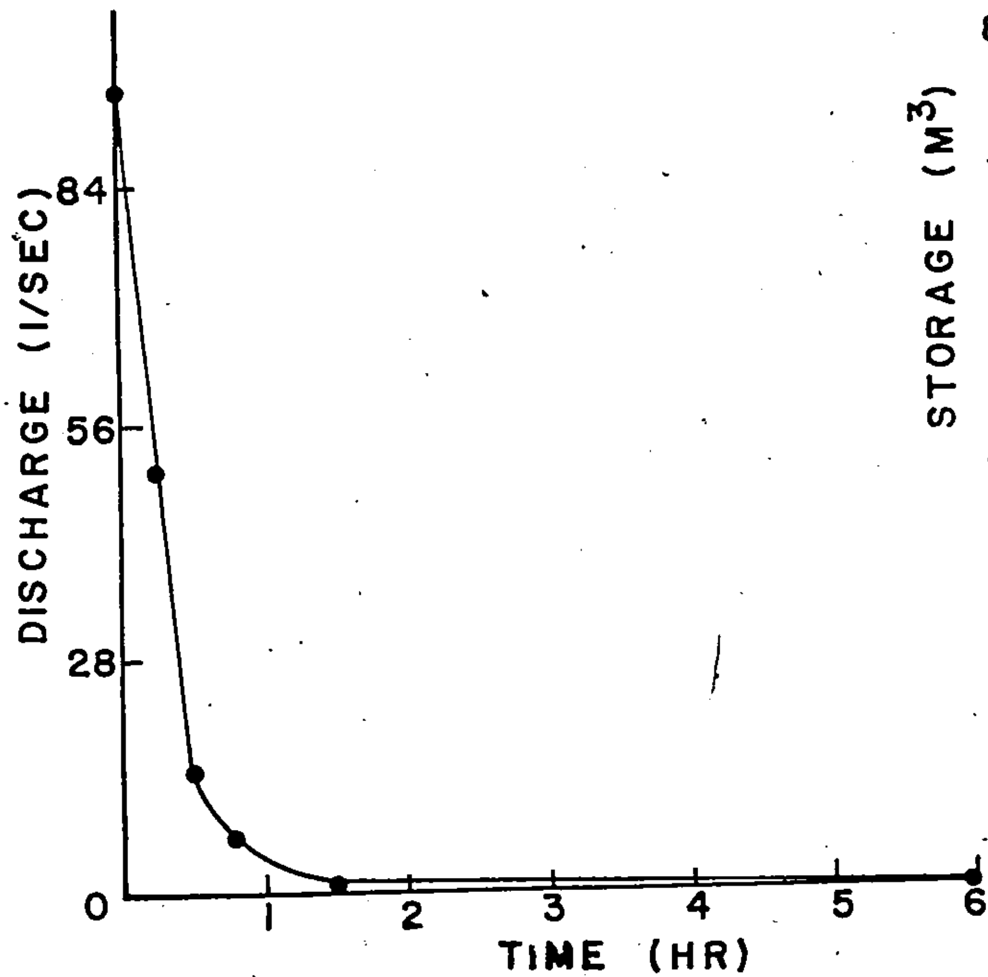


FIG. 4-7. AVERAGE RECESSION CURVE

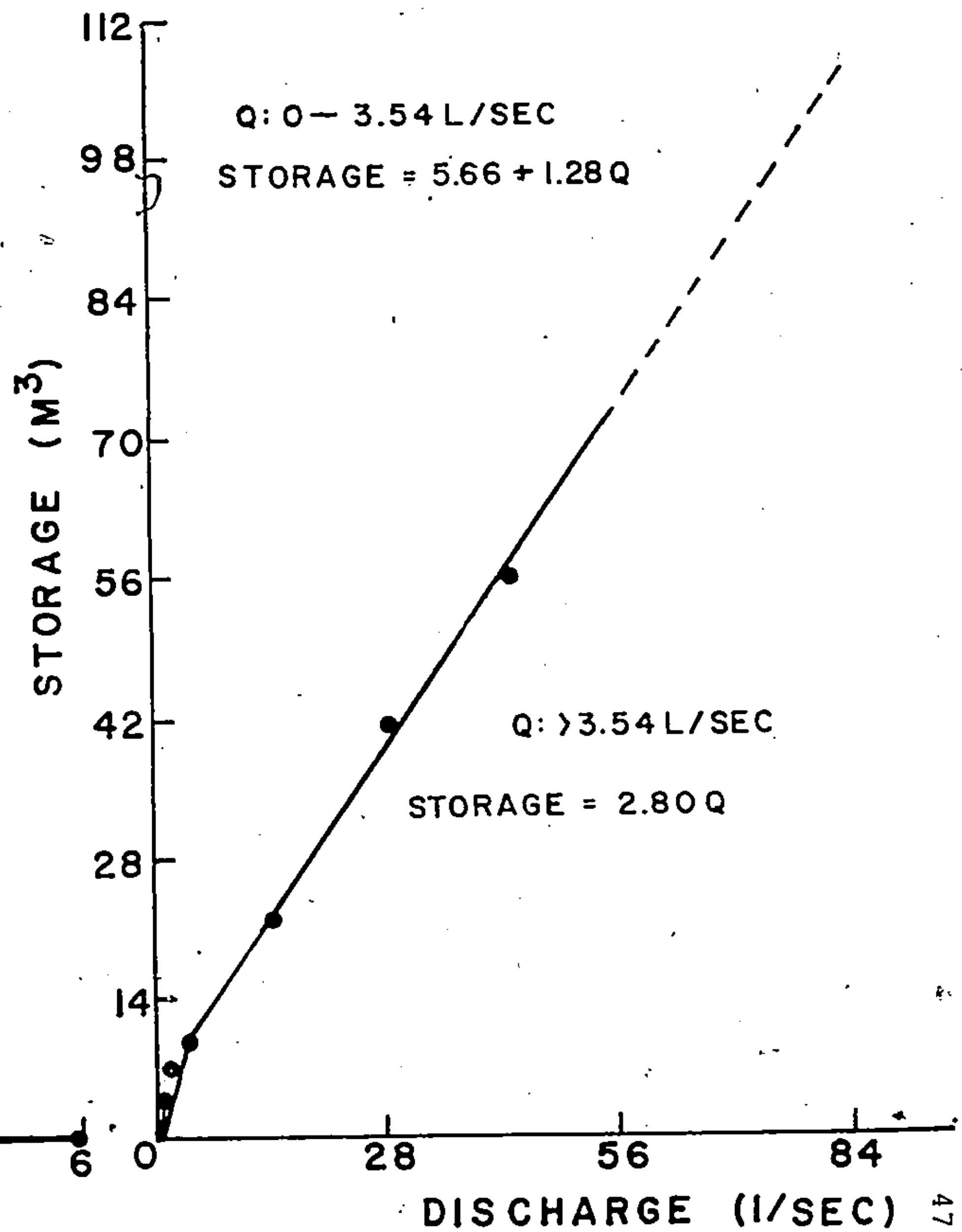


FIG. 4-8. STORAGE-DISCHARGE RELATION

generated hydrograph are compared in Figure 4-9(a). Average hourly discharges are compared in Fig. 4-9(b). The agreement between average hourly flows is good but the peaks in the recorded hydrograph do not appear in the synthetic hydrograph. In checking the RRL hydrograph against a particular recorded hydrograph, the runoff coefficient C_i of the storm of interest was used in the RRL program. Nine storms with recorded hydrographs were run using the RRL program, agreement was reasonable in 6 out of the 9. The storm of Mar. 11 (Fig. 4-9(b)) is typical of the agreement reached in average hourly flow values.

The program was then applied to the storms with unknown hydrographs determining average hourly discharges which are graphed in Appendix A. Samples were usually taken on an hourly basis. If there was a 2-hour or more gap between samples, the average discharge for the 2-hour or more time period was graphed.

4.3.4 Storms in which Significant Snowfall Occurred

The storms of Nov. 25-26 and Jan. 23-24 were due almost wholly to snowfall. Since meltoff would not occur in the same manner as runoff, no attempt was made to synthesize their hydrographs.

In the storm of Dec. 12-13 snow had fallen earlier in the day. The rain that occured later on, completely removed the snow with its runoff. The total amount of runoff that the snow produced was

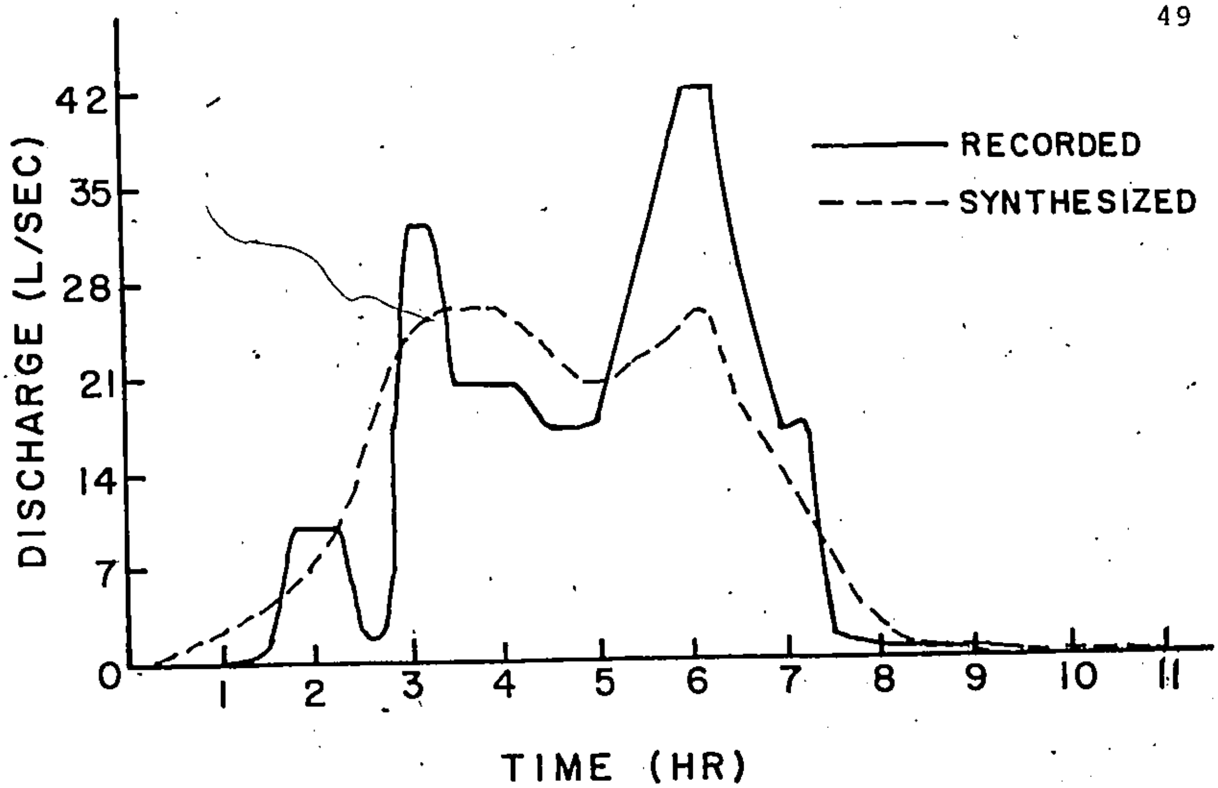


FIG. 4-9(a). SYNTHESIZED AND ACTUAL HYDROGRAPHS FOR STORM OF MAR. 11, 1973.

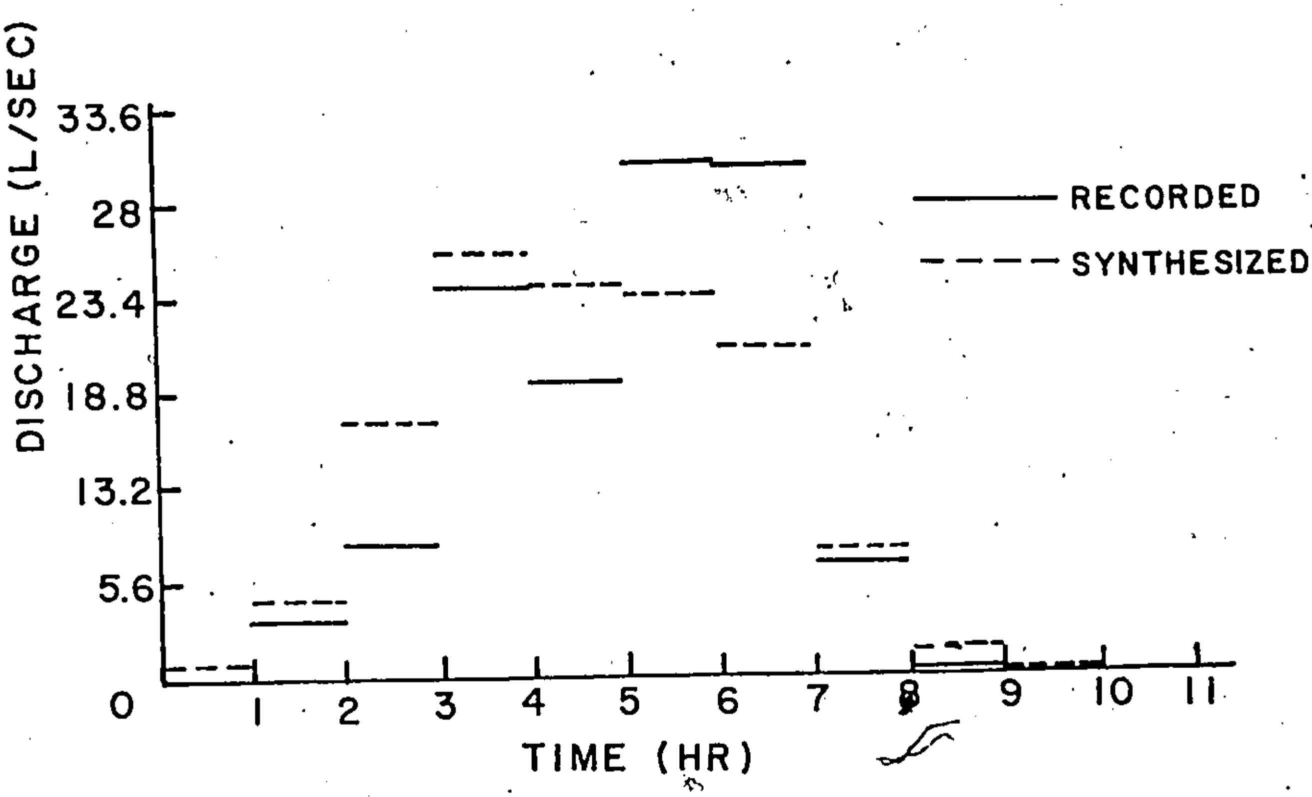


FIG. 4-9(b). SYNTHESIZED AND ACTUAL HOURLY DISCHARGES FOR STORM OF MAR. 11, 1973.

proportionately divided and added on to the first 16 hours of runoff.

Chapter V

SAMPLE COLLECTION, ANALYSES AND OBSERVATIONS

5.1 Sample Collection

The experimental setup at the site is shown in Fig. 5-1. An automatic grab sampler supplied by Testing Machines International was used with a specially designed filter head to intercept low depth flows in the sewer (see Fig. 5-2). Due to high discharges resulting from heavy rainfall in March and thereafter, the sampling head was anchored to the bottom of the sewer. The sampler collected one sample each hour except for the storm of Dec. 12-13, 1972 when samples were collected at two hour intervals due to malfunctioning of the timer mechanism. After this two samplers were frequently placed in the manhole to insure that all samples were collected.

5.2 Methods of Analyses

After collection the samples were refrigerated between 0 - 5°C to minimize microbial activity. The following nineteen analyses were made on almost every sample collected: pH, colour, turbidity, specific

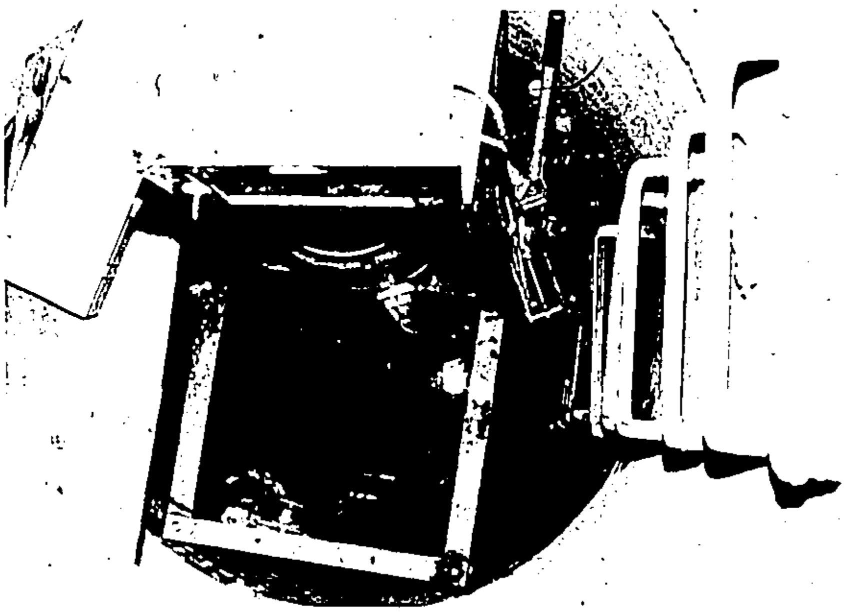


Fig. 5-1. The Equipment Setup at the Experimental Site.

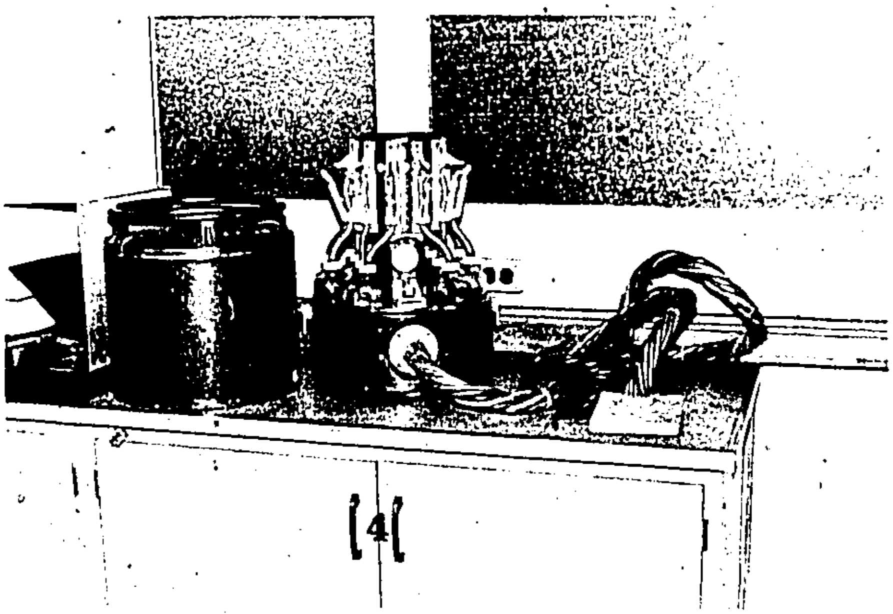


Fig. 5-2. The Automatic Sampler and Filter Head.

conductance, TSS, VSS, phenolphthalein alkalinity, total alkalinity, calcium hardness, total hardness, chlorides, sulfates, orthophosphates, ammonia, nitrates, nitrites, BOD, total coliform and fecal coliform. Turbidity and colour measurements were not begun until Mar. & Jan. respectively. Temperature of the runoff in the sewer was measured for each storm and a grease and oil determination was made on a composite runoff sample for most storms.

The analyses were performed in accordance with procedures in Standard Methods for the Examination of Water and Wastewater [21]. Instruments and the particular method used with any variations are described below for each test. All colorimetric tests were made on the filtrate from a sample. Sample bottles were washed with detergent, rinsed three times with tap water and then rinsed twice with distilled water before being autoclaved with their caps loosely fitted.

Temperature was measured by dipping a standard thermometer into the flow. pH was measured with a Fisher Acumet pH meter, model 210. Colour was measured with an Hellige Aqua Tester after suspended solids were allowed to settle in the sample. Turbidity was, in most cases, measured by a Jackson Candle Turbidemeter, low turbidities (below 50 JTU) were measured by the Hach Laboratory Turbidimeter, Model 1860A. A conductivity meter, type CDM2e from

Radiometer Inc. was used for measuring specific conductance. Total suspended solids (nonfilterable residue) and volatile suspended solids were determined using Gooch crucibles. Phenolphthalein indicator was used to determine phenolphthalein alkalinity and methyl orange was chosen to indicate total alkalinity. EDTA titrimetric methods were employed in determining calcium and total hardness. Chlorides were measured by the Argentometric Method and sulfates by the turbidimetric method. Orthophosphates were measured by the stannous chloride method adapted to the Pye Unicam AC60 Chemical Processing Unit and SP500, Series 2 Spectrophotometer. Ammonia was determined by the Nesseralization Method, nitrates by the Brucine-Sulfanilic Acid Method [22], and nitrites by the colorimetric method. The BOD was measured at 20°C for 5 days. For the determination of dissolved oxygen the Galvanic Cell Oxygen Analyzer (manufactured by Precision Scientific Co.) or the Yellow Springs Instruments, Model 54, oxygen meter was used. The Millipore membrane filter procedures were used in determination of total and fecal coliform densities. The Soxhlet Extraction Method was used to measure grease and oil content.

The following tests were performed or started as soon as possible after a storm had ended: pH, BOD and total and fecal coliform.

5.3 Runoff Quality

A total of 241 samples were taken of which 215 were pertinent to the 25 storms sampled in Table 3-4. For most of the data analyses samples taken when the discharge was less than 0.28 ℓ/sec. (0.01 cfs.) were not considered; only 182 samples were used in this case. All of the constituents except for grease and oil and colour are plotted in Appendix A for each hour sampled of each storm. The exact measured values of all the constituents and the average sewer discharge for the one, two or three hour period (depending on the gap between samples) around the time of a sample are tabulated in Appendix D.

In Table 5-1 the average seasonal and annual values for the constituents are given along with their ranges and standard deviations. From scanning the graphs in Appendix A, it is observed that the concentration of dissolved constituents generally rises rapidly as runoff ceases. These concentrations are very close to dry weather flow concentrations. This is further discussed in Chapter VII. For this reason all samples taken when the flow was less than 0.28 ℓ/sec (0.01 cfs.) were ignored in Table 5-1. In terms of runoff these neglected samples represent less than 0.1% of the total amount of runoff sampled. These very low discharges almost always occurred at

Table 5-1

Observed Average Quality of Runoff[1]

Constituent	Annual Mean	Range	Standard Deviation	Winter Mean	Spring Mean	Summer Mean	Fall Mean
BOD, mg/ℓ	20.5	0-78.4	14.0	17.7	20.8	26.8	18.2
Total Coliform, (#/100 ml) x 10^{-3}	64	0.2-1200	170	4.0	16.0	270	26
Fecal Coliform, (#/100 ml) x 10^{-2}	82	0.1-2000	270	6.9	39.0	350	9.2
TSS, mg/ℓ	279	23-1230	245	278	467	384	111
VSS, mg/ℓ	112	0-392	92	129	97	138	36
Ammonia, mg/ℓ[2]	0.054	0-0.710	0.077	0.033	0.050	0.050	0.085
Nitrates, mg/ℓ[2]	1.16	0-4.70	0.74	1.05	1.14	1.37	1.14
Nitrites, mg/ℓ[2]	0.066	0.001-.570	0.066	0.066	0.070	0.094	0.045
Orthophosphates, mg/ℓ	0.437	0-2.500	0.444	0.299	0.634	0.601	0.316
Chlorides, mg/ℓ	72	4-1585	166	122	48	29	59
Sulfates, mg/ℓ	46.0	1-220	38.5	56.8	34.5	37.8	46.2
Phenolphthalein Alkalinity, mg/ℓ[3]	0	0	0	0	0	0	0
Total Alkalinity, mg/ℓ[3]	115	40-344	62	123	120	108	108
Calcium Hardness, mg/ℓ[3]	100	40-272	46	108	97	102	92
Total Hardness, mg/ℓ[3]	151	55-504	98	158	131	142	163
pH[4]	7.40	6.75-8.02	0.23	7.50	7.39	7.30	7.37
Colour, Unit	160	45-440	82	204	144	99	--
Turbidity, JT4	363	50-1200	225	360	414	304	--
Sp. Conductance, milli-mhos/cm	0.352	0.065-2.390	0.312	0.425	0.295	0.294	0.343
Grease and Oil, mg/ℓ	18.7	8.9-39.0	--	15.1	17.9	24.3	19.2
Temperature, °C	10.9	4.0-18.5	--	5.3	10.9	14.9	12.8

(1) Samples for discharge less than 0.28 ℓ/sec not included. (2) mg/ℓ as N.
(3) mg/ℓ as $CaCO_3$. (4) Arithmetic means, range and std. deviation.

the end of runoff and in a couple of cases occurred in the beginning.

The average concentration of each constituent in the beginning, middle and ending periods of all storm runoff periods is shown in Table 5-2. The duration of each individual storm runoff period was divided as nearly as possible into three equal periods, then averages were taken for each period. Most of the runoff volume occurred in the first two periods.

5.4 Loadings

To determine seasonal and annual pollution loadings for stormwater runoff for this area, the measured constituent concentrations were multiplied by their respective average discharge for each hour of each storm. If there was a one hour gap between samples, the average discharge was calculated over a time period of one-half hour before and after the time of sampling; for a two hour gap the average discharge was calculated over one hour before and after the time of sampling and so on. Then for each season the average load of each constituent of stormwater runoff per centimeter of rainfall was calculated by summing the total loads of constituent from all storms in that season. The total load was then divided by the total amount of rainfall responsible for the storm discharges in that season. This load per centimeter

Table 5-2
Change in Runoff Quality with Time[1]

Constituent	First Third of Runoff Duration	Second Third of Runoff Duration	Last Third of Runoff Duration
BOD, mg/ℓ	22.1	21.4	18.3
Total Coliform, (#/100 ml) x 10^{-3}	100	49	47
Fecal Coliform, (#/100 ml) x 10^{-2}	159	61	37
TSS, mg/ℓ	333	312	200
VSS, mg/ℓ	136	121	81
Ammonia, mg/ℓ[2]	0.08	0.06	0.03
Nitrates, mg/ℓ[2]	1.22	1.01	1.22
Nitrites, mg/ℓ[2]	0.097	0.059	0.047
Orthophosphates, mg/ℓ	0.443	0.438	0.440
Chlorides, mg/ℓ	101	66	53
Sulfates, mg/ℓ	54.2	37.7	45.9
Total Alkalinity, mg/ℓ[3]	132	102	112
Calcium Hardness, mg/ℓ[3]	112	90	95
Total Hardness, mg/ℓ[3]	172	126	154
pH[4]	7.40	7.42	7.39
Colour, Unit	161	171	147
Turbidity, JTU	418	416	276
Sp. Conductance milli-mhos/cm	0.438	0.298	0.323

(1) Samples for discharge less than 0.28ℓ/sec not included.
(2) mg/ℓ as N.
(3) Mg/ℓ as $CaCO_3$.
(4) arithmetic means.

of rainfall was multiplied by the 30 year average total rainfall in that season (Table 3-7) to obtain the seasonal loading. The annual loading is the sum of the seasonal loadings. The storms of Nov. 25-26 and Jan. 23-24 were not used in this calculation since no discharges were available for them. Also, the storm of Oct. 21 was not used because only the last half of it was sampled. The loadings are listed in Table 5-3. Grease and oil in runoff were found to be removed fairly rapidly by Warnock [33]. They were assumed to be similar to removal of chlorides in estimating their annual loading in Table 5-3. The high chloride loading calculated for fall was due to the influence of high chloride concentrations measured for the snow-rain storm of Dec. 12-13.

The average hourly loadings for the storms sampled, exclusive of Oct. 21, Nov. 25-26, and Jan. 23-24, are shown in Table 5-4. Values for hour one were obtained by averaging the load for each constituent of each sample taken in the first hour of runoff; hour number two values are average loads for each sample taken in the second hour of runoff and so forth. Except for coliform counts the loadings of all constituents after hour 8 were equal to or less than their loadings at hour 8. It must be remembered that storms of different length constitute the averages in this table.

Table 5-3

Seasonal and Annual Constituent Loadings[(1),(3)]
in kg./ha.

Constituent	Winter	Spring	Summer	Fall	Annual
BOD	3.2	9.6	6.8	4.5	24.1
TSS	125.6	294.5	147.9	41.9	609.9
VSS	50.1	93.1	39.4	15.8	198.4
Ammonia as N	0.009	0.031	0.016	0.011	0.067
Nitrate as N	0.251	0.460	0.354	0.194	1.259
Nitrite as N	0.018	0.030	0.020	0.010	0.078
Orthophosphates	0.096	0.299	0.173	0.083	0.651
Chlorides	19.3	13.8	5.3	37.0	75.4
Sulfates	11.9	11.1	8.7	7.1	38.8
Total Alkalinity as $CaCO_3$	36.2	54.2	29.7	19.4	139.5
Calcium Hardness as $CaCO_3$	27.9	35.3	26.6	16.7	106.5
Total Hardness as $CaCO_3$	38.2	44.8	35.4	28.3	146.7
Grease and Oil[(2)]	--	--	--	--	20.1

(1) Storms of Oct. 21, Nov. 25-26, and Jan. 23-24 not included.

(2) Estimated.

(3) Samples with discharge less than 0.25 ℓ/sec. not included.

Table 5-4
Average Hourly Constituent Loads for the Year(1),(2)
in kg/hr

Constituent	Hour 1	2	3	4	5	6	7	8
BOD	1.27	0.59	0.50	0.59	0.59	0.27	0.50	0.23
Total Coliform x 10^{-9}(3)	120	220	62	66	130	24	220	40
Fecal Coliform x 10^{-8}(3)	104	350	74	120	160	32	290	21
TSS	36.2	22.1	10.2	20.7	12.5	8.4	12.6	2.4
VSS	7.1	5.1	2.7	5.0	2.7	2.0	2.7	1.4
Ammonia as N	0.0037	0.0015	0.0010	0.0029	0.0019	0.0014	0.0007	0.0002
Nitrate as N	0.046	0.043	0.034	0.032	0.020	0.020	0.021	0.013
Nitrite as N	0.0037	0.0029	0.0022	0.0022	0.0020	0.0011	0.0012	0.0006
Orthophosphates	0.035	0.035	0.014	0.012	0.020	0.008	0.009	0.005
Chlorides	2.0	2.5	2.0	1.7	0.7	0.9	2.2	0.5
Sulfates	1.5	1.2	1.0	1.2	0.7	0.7	1.3	0.5
Total Alkalinity as $CaCO_3$	7.1	5.0	2.7	5.0	2.7	2.0	2.7	1.4
Calcium Hardness as $CaCO_3$	4.5	3.5	2.2	3.3	1.9	1.9	2.7	1.5
Total Hardness as $CaCO_3$	5.9	4.6	3.2	4.9	2.4	2.5	3.5	1.8

(1) Storms of Oct. 21, Nov. 25-26, Jan. 23-24 not included.
(2) Samples with less than 0.28ℓ/sec discharge, not included.
(3) Listed as #/hr.

The data were also separated seasonally and average hourly loads were calculated as above. Winter and fall were more uniform in loadings for the first seven hours than spring or summer, however, in the four individual seasons, all the average loadings (except for coliform counts) fall considerably after six to seven hours as shown in Table 5-4.

5.5 Relationships Among the Constituents

By computer, Pearson product-moment correlation coefficients were calculated for each pair of constituents and average discharge, all constituents were considered. All coefficients equal to or higher than 0.70 appear in Table 5-5. The number of variable pairs used for the annual correlations was usually above 194, for winter the number was usually above 70, spring the number was usually above 39, summer- 37 and fall- 45. From the table it is observed that total hardness - calcium hardness, total hardness - sulfates, TSS - turbidity and specific conductance - chlorides have better coefficients for each season and annually. Other pairs such as total alkalinity - total hardness and total coliform - fecal coliform exhibited varying correlation. This table and known relationships among the constituents were considered in hypothesizing relationships among them and applying regression analyses. Only linear models were considered.

Table 5-5

Correlation Coefficients Between Constituents

Variable Pair	Winter	Spring	Summer	Fall	Annual
Total Alkalinity-Total Hardness	0.87	0.58	0.98	0.99	0.89
Total Hardness-Calcium Hardness	0.98	0.98	0.98	0.85	0.94
Total Alkalinity-Sulfates	0.69	0.40	0.95	0.93	0.78
Total Hardness-Sulfates	0.88	0.87	0.97	0.96	0.92
Total Coliform-Fecal Coliform	0.34	0.49	0.96	0.26	0.96
TSS-Tuibidity	0.88	0.83	0.82	-	0.80
Chlorides-Sp. Conductance	0.89	0.97	0.99	0.87	0.85
TSS-VSS	0.71	0.87	0.59	0.58	0.76
Total Alkalinity-Calcium Hardness	0.85	0.54	0.98	0.83	0.85
Calcium Hardness-Sulfates	0.86	0.87	0.98	0.78	0.84
Total Alkalinity-Nitrates	0.71	0.19	0.61	0.70	0.61
Calcium Hardness-Nitrates	0.82	0.25	0.70	0.64	0.69
Total Hardness-Nitrates	0.81	0.23	0.64	0.74	0.68
Total Hardness-Sp. Conductance	0.45	0.97	0.99	0.74	0.66
Calcium Hardness-Sp. Conductance	0.48	0.97	0.99	0.68	0.65
Sp. Conductance-Sulfate	0.39	0.87	0.98	0.75	0.63
Calcium Hardness-Chlorides	0.17	0.92	0.98	0.28	0.29
Total Hardness-Chlorides	0.14	0.94	0.98	0.36	0.27
Total Alkalinity-Sp. Conductance	0.60	0.49	0.98	0.70	0.69
Total Alkalinity-Chlorides	0.37	0.53	0.96	0.31	0.39
Sulfate-Nitrate	0.60	0.12	0.72	0.73	0.57

5.5.1 Specific Conductance

Singh [7] observed a primary dependence of specific conductance on chlorides during winter while sulfates as well had a significant influence during the rest of the year. For the year's data, the model assumed involved chlorides, calcium hardness, magnesium hardness (magnesium hardness = total hardness - calcium hardness), orthophosphates, total alkalinity, nitrates, nitrites, VSS, sulfates and ammonia as independent variables determining specific conductance. The maximum R-Square improvement and stepwise regression procedures described by Draper and Smith [23] were used. All the preceding variables except sulfates, ammonia and VSS were determined significant at the 10 per cent level in the model, however analysis of variance statistics were very good using only chlorides and calcium hardness for the model. Addition of the other independent variables resulted in little improvement in statistics. R-Square value is the square of the multiple correlation coefficient. In Table 5-6 are some statistics for the various models.

The slopes of all the regression lines were significant from zero at a 1% level for chlorides alone; or for calcium hardness and chlorides the intercept and slope terms were significant from zero at a 0.1% level. Chlorides is the best single independent

Table 5-6

Statistics of Fit for Various Specific Conductance Models

	F-Value	Significance Probability of F(%)	R-Square	Coefficient of Variation (%)
Chlorides	657	0.1	0.792	41.1
Chlorides - Calcium Hardness	1029	0.1	0.923	25.0
All 7 Independent Variables Significant at 10% Level	350	0.1	0.936	23.1

variable but the chloride-calcium hardness model is the most accurate practical model. The predicted equation was

$$\text{Specific Conductance} = 0.0089 + 0.0015\,[Cl^-] + 0.0023\,[Ca^{++}\ \text{Hardness}]$$

where Ca^{++} hardness is mg/ℓ as $CaCO_3$.

Table 5-5 also shows that sulfates, total alkalinity and other ions all correlated well with specific conductance in the summer and the coefficients were quite high in spring. For regression analyses on summer data alone, the chloride-calcium hardness model was again best. However, calcium hardness was more significant than chlorides in determining specific conductance. The predicted equation and other statistics are below.

$$\text{Specific Conductance} = -0.049 + 0.0025\,[Cl^-] + 0.0030\,[Ca^{++}\ \text{Hardness}]$$

R-Square Value = 0.979
F-Value = 600 at 0.01% significance level
Coefficient of Variation = 10.5%
where Ca^{++} hardness is mg/ℓ as $CaCO_3$.

The statistics for the summer equation show it to be quite reliable.

5.5.2 Relationships Among Total Hardness, Calcium Hardness and Sulfates

The correlation between total hardness and calcium hardness was very good for the year's data. It is noted from Table 5-5 that the correlation coefficients were above 0.80 for each season and the year. The regression equation and other statistics are listed below. All hardness data are in mg/ℓ as $CaCO_3$.

[Calcium Hardness] = 31.1 + 0.50 [Total Hardness]

F-Value = 2058 at 0.01% significance level
R-Square Value = 0.95
Coefficient of Variation = 10.6%
Intercept and slope terms were significant from zero at 0.1% level.

Figure 5-3 is a plot of calcium hardness versus total hardness.

Regression analysis on sulfates and total hardness yielded the following results:

$[SO_4^=]$ = 0.29 [Total Hardness]

F-Value = 727 at 0.01% significance level
R-Square Value = 0.88
Coefficient of Variation = 23.9%
Slope term significant from zero at 0.1% level.

Sulfates are plotted against total hardness in Fig. 5-4. It is noted that calcium hardness and sulfates also had good correlation but not as good as total hardness and sulfates.

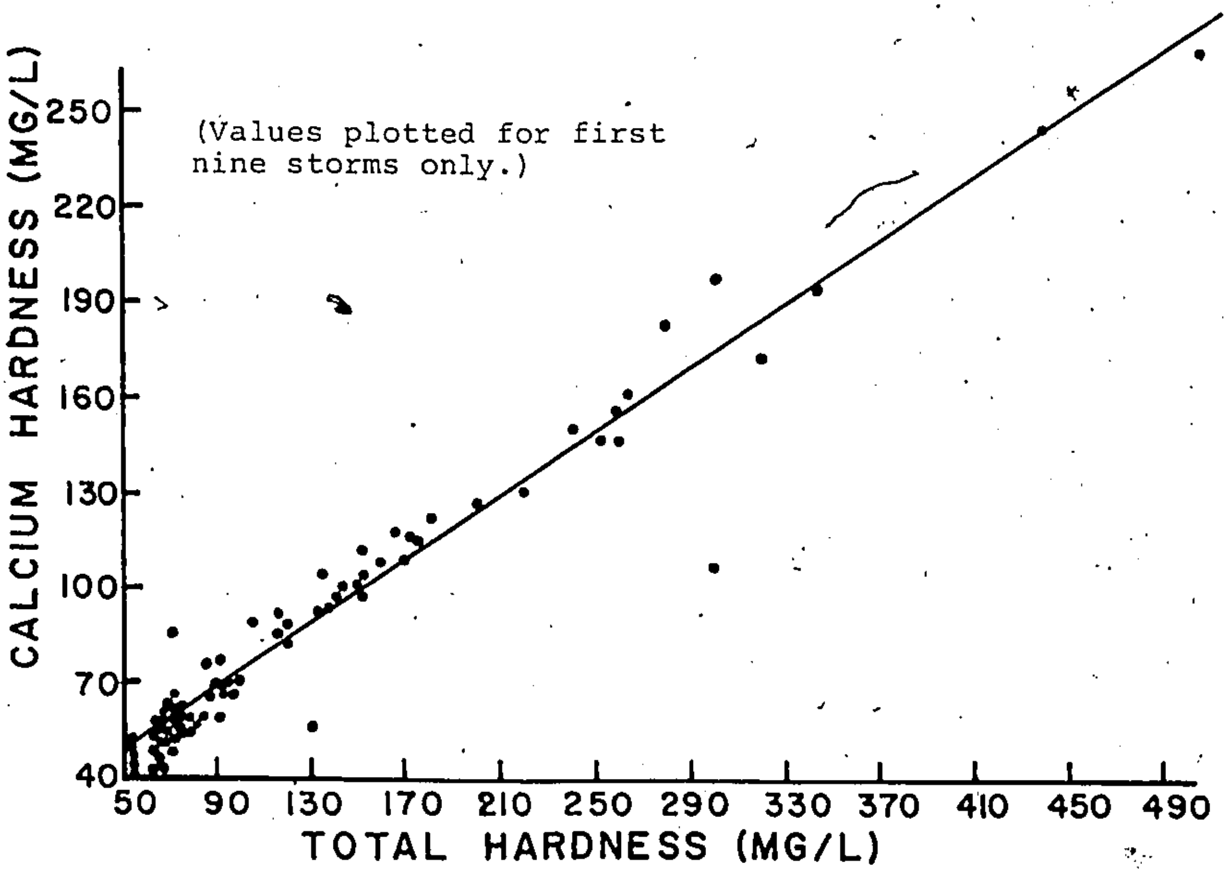


FIG. 5-3. CALCIUM HARDNESS - TOTAL HARDNESS RELATION.

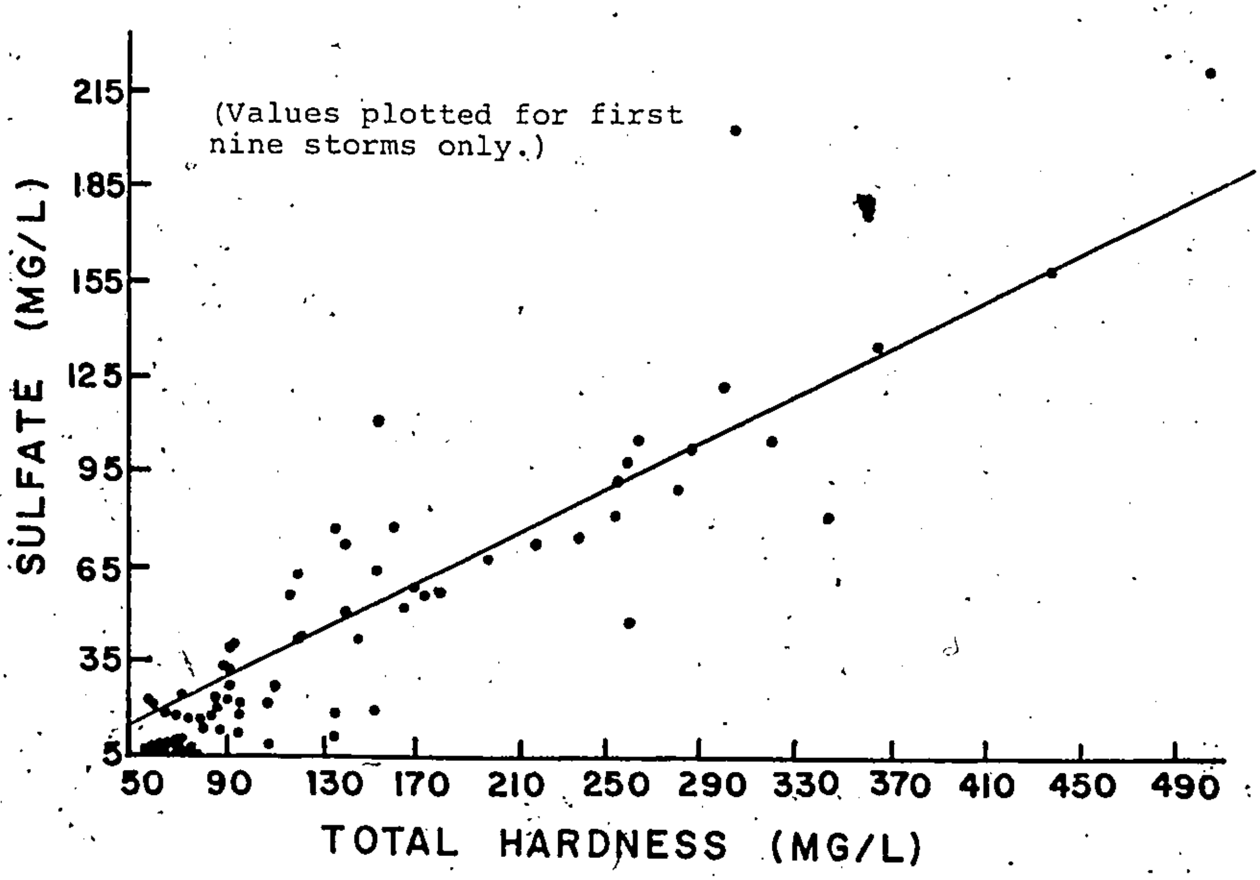


FIG. 5-4. SULFATE - TOTAL HARDNESS RELATION.

5.5.3 Total Alkalinity and Hardness

Correlation between total alkalinity and either total hardness or calcium hardness was good except in spring. Total alkalinity exhibited a trend of relatively lowering its correlation in spring with all constituents except chlorides. A regression analysis on total alkalinity and total hardness for spring's data only showed the predicted equation to be very poor. The R-square value was only 0.34, other statistics were low. The regression applied to data for the remaining three-fourths of the year produced the following:

[Total Alkalinity] = 020.4 + 15.8 [Total Hardness]

F-Value = 1055 at 0.01% significance level
R-Square Value = 0.86
Coefficient of Variation = 25.8%
Intercept and slope terms different from zero at
0.4% significance level.
where alkalinity and hardness are mg/ℓ as $CaCO_3$.

Total alkalinity versus total hardness is plotted in Fig. 5-5 (spring data are omitted).

5.5.4 TSS, Turbidity and Discharge

Turbidity should generally reflect total suspended solids content of a sample. Regression analysis generated the following equation and statistics.

Turbidity (JTU) = 84.1 + 0.71 [TSS]

F-Value = 175 at 0.01% significance level
R-Square Value = 0.64
Coefficient of Variation = 46.1%

The standard error of the intercept term was 23.7. Figure 5-6 is a plot of turbidity against TSS, showing the predicted line.

Attempts to derive a relationship between TSS and discharge (dependent on rainfall intensity) were unsuccessful. Plotting TSS against average discharge for each hour, showed no general trends. From scanning the graphs in Appendix A, it is apparent that TSS increased as discharge increased, although the average TSS level varied for each storm. A computer program that divided the range of discharge for a storm into 10 equal intervals and ranked the intervals from 1 through 10 was executed. A discharge value was assigned the rank of the interval in which it fell. Similarly, the TSS values were ranked for each individual storm. For example:

Storm	Discharge (ℓ/sec.)	5.7	1.4	0.85	2.9	4.4	1.1
	Rank	10	2	1	5	8	1
	TSS (mg/ℓ)	290	100	58	150	206	50
	Rank	10	3	1	5	7	1

This procedure was performed on each storm separately and the ranked, paired values of TSS and discharge are plotted against each other in Fig. 5-7. If for each

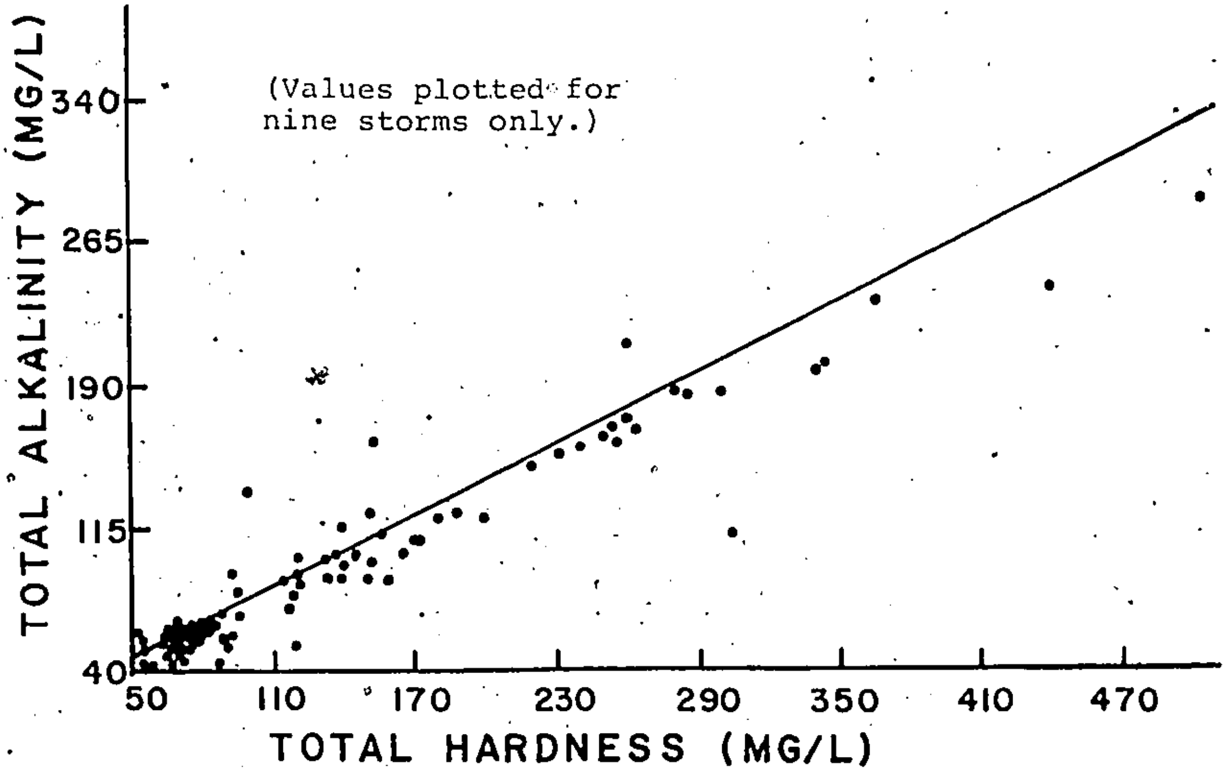


FIG. 5-5. TOTAL ALKALINITY - TOTAL HARDNESS RELATION FOR ALL SEASONS EXCEPT SPRING.

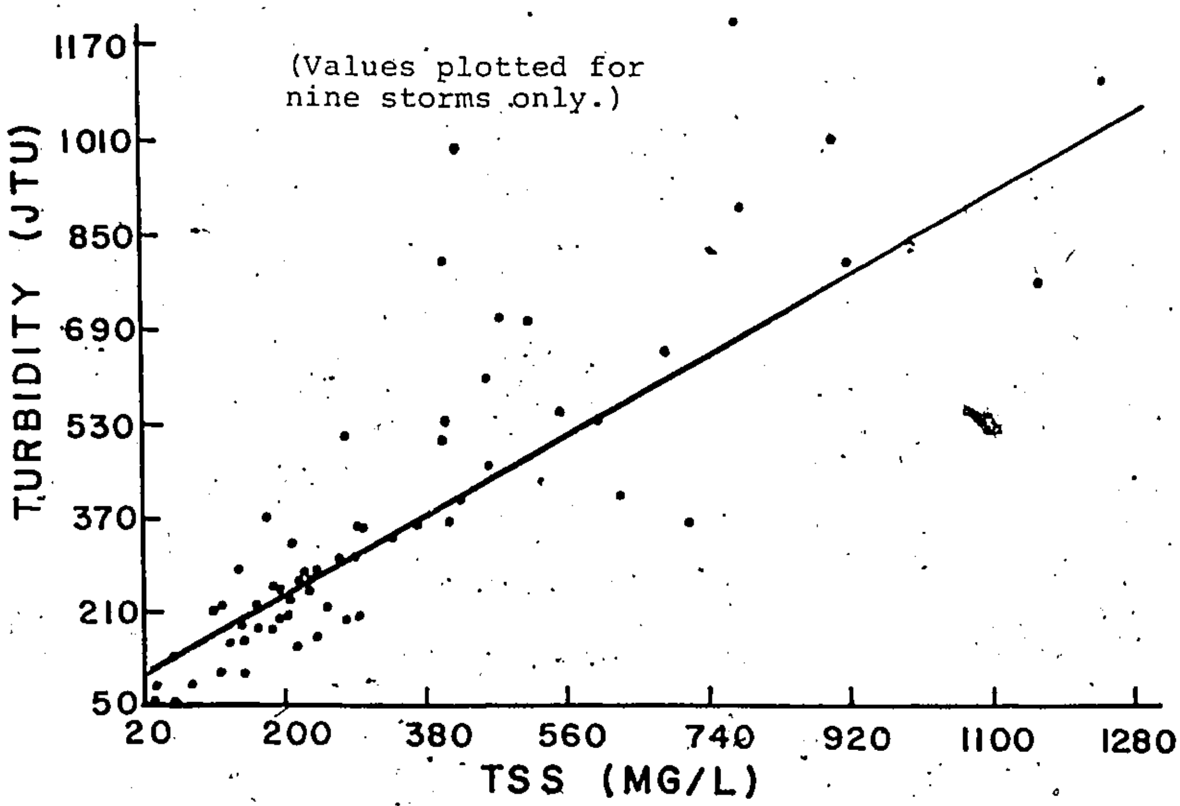


FIG. 5-6. TURBIDITY - TSS RELATION.

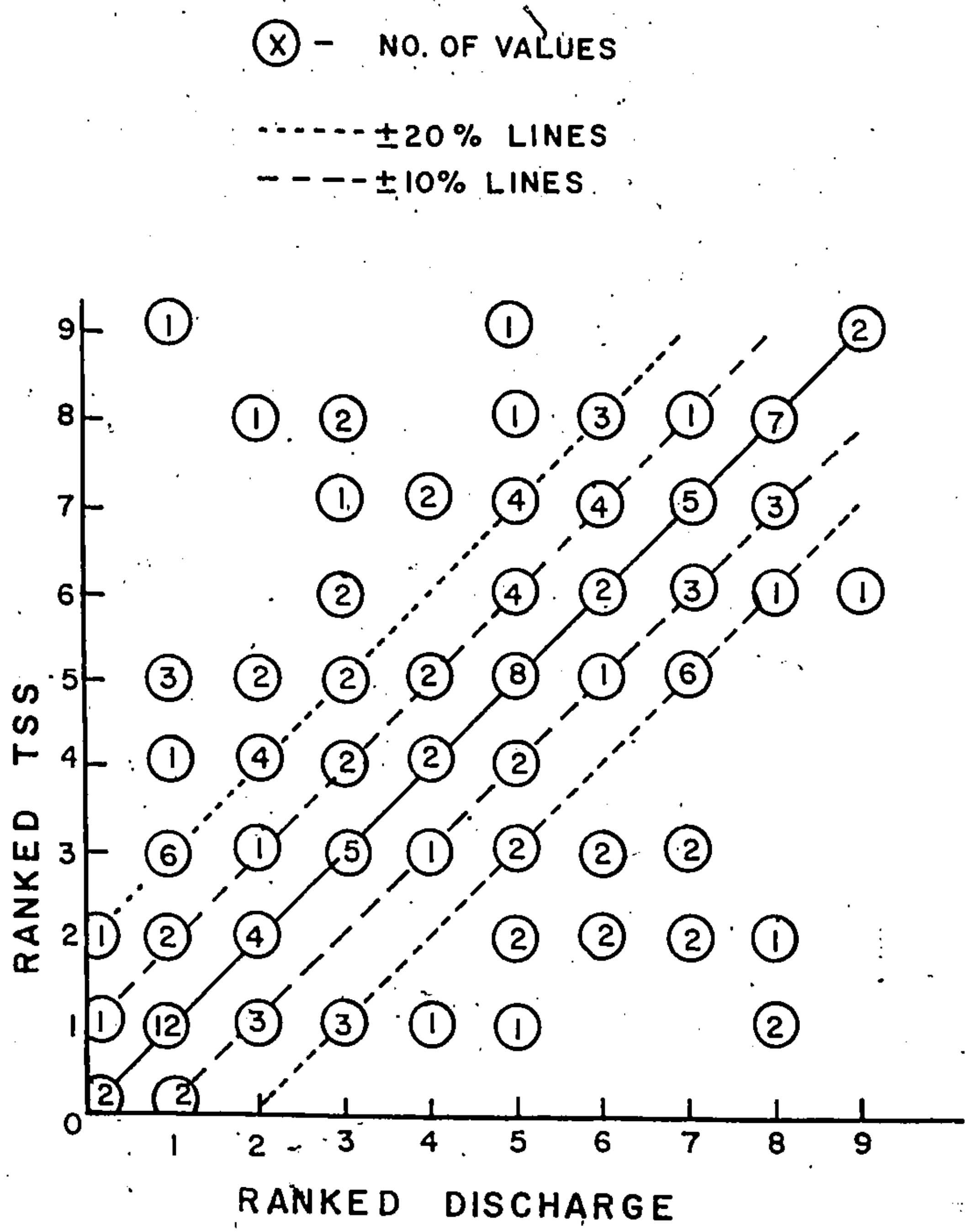


FIG. 5-7. EFFECT OF INCREASED DISCHARGE ON TSS.

storm a change in discharge produced a proportionate change in TSS all points would fall on a 45° line through the origin of the graph, that is, each TSS and discharge pair would have the same rank. In Fig. 5-7, 32.0% of the points fall on the 45° line, 20.9% of the points are made of TSS - discharge pairs that are within ± one rank of the 45° line and 24.2% of the points are within two ranks of the 45° line. Seventy-seven per cent of the points are within two or less ranks of each other, giving a definite indication of increased TSS due to increased discharge.

Weibel et al. [24] found good agreement between mean suspended solids concentration found within different ranges of discharge. Figure 5-8 is a similar graph for data gathered in this study.

5.5.5 Other Correlations

In a stepwise procedure [23] the dependence of BOD upon TSS, VSS, nitrates, nitrites, ammonia, orthophosphates, sulfates, total coliform, specific conductance and total alkalinity was tested. Nitrites, VSS and ammonia were all deemed significant at a 0.1 level but the model was poor. The R-square values was only 0.260 and the standard errors of the coefficients in the predicted equation were equal to ±25% or more of the coefficient values.

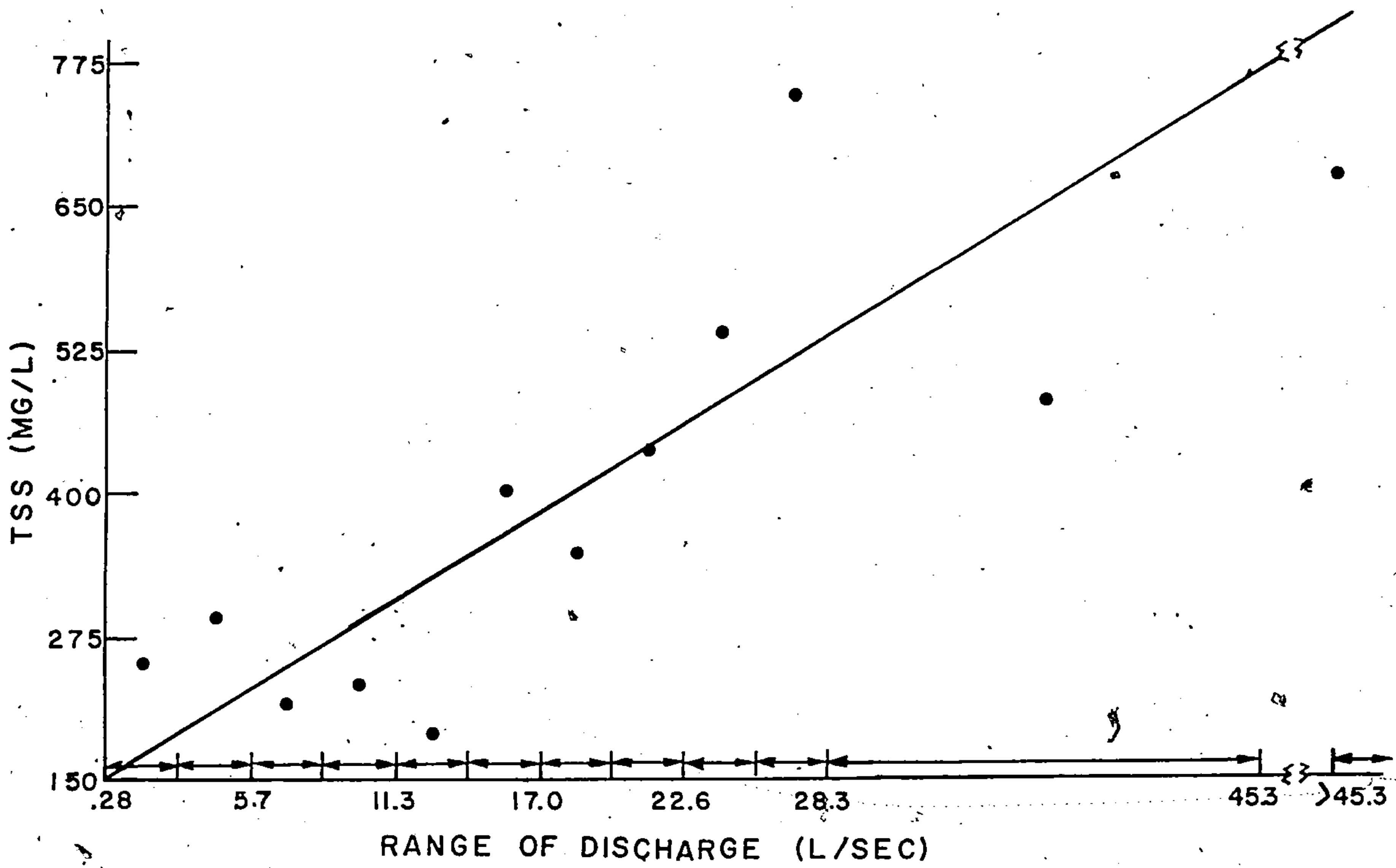


FIG. 5-8. AVERAGE TSS IN DIFFERENT RANGES OF DISCHARGE.

Total coliform and fecal coliform had a high correlation coefficient for summer which dominated the other coefficients for the total year's data. This was due to the higher counts measured in the summer; they were about a factor of ten or more higher than counts for other seasons. The relatively greater spread of summer data made this period more significant in determining the regression equation for the year.

The predicted equation for summer data only was

Fecal Coliform (#/100 ml) = -7339 + 0.151 (Total Coliform (#/100 ml)

F-Value = 468 at 0.01% significance level
R-Square Value = 0.93
Coefficient of Variation = 44.6%
Intercept and slope terms were significant from zero at a 1.2% significance level.

It should be mentioned that in summer, total hardness, total alkalinity, calcium hardness, sulfates and chlorides all correlated well with each other and also with specific conductance. A good correlation between TSS and VSS was not found.

5.6 Dilution Phenomena

Singh [7] and others [3] found dilution phenomena, decrease in concentration of a substance with increased discharge, to pertain to some constituents. For the year's data, each constituent was plotted against discharge. By eye examination of the plots, a judgement of a constituent's dilution phenomena behaviour was made. The behaviour was separated into three classes: (1) good, (2) some and (3) none at all. Falling in class (1) were specific conductance, total and calcium hardness, sulfates, chlorides, total and fecal coliform, nitrates and nitrites; in class (2) were total alkalinity and orthophosphates and the remaining constituents were in class (3). Typical plots of classes (1) and (2) are shown in Figures 5-9(a) and (b).

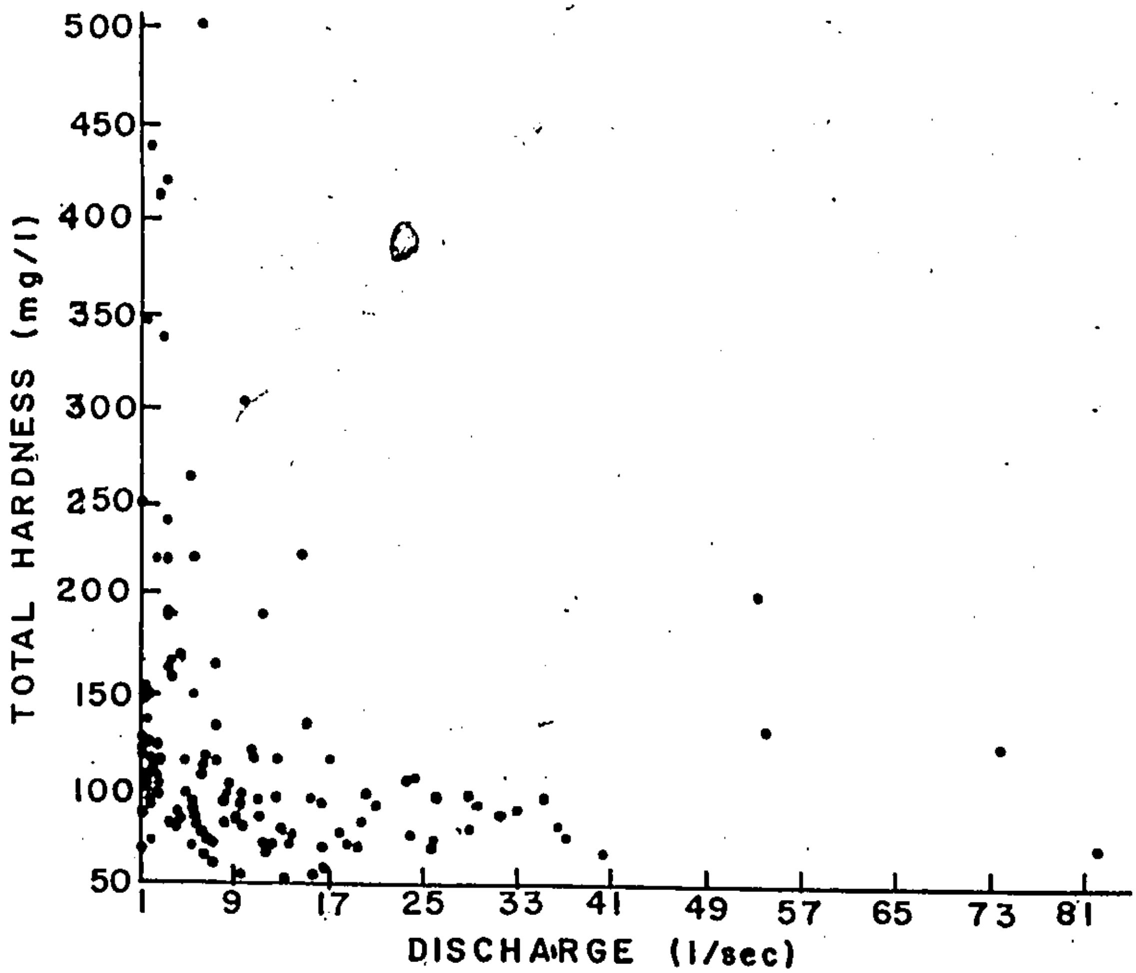


FIG. 5-9(a). DILUTION PHENOMENA, CLASS (1).

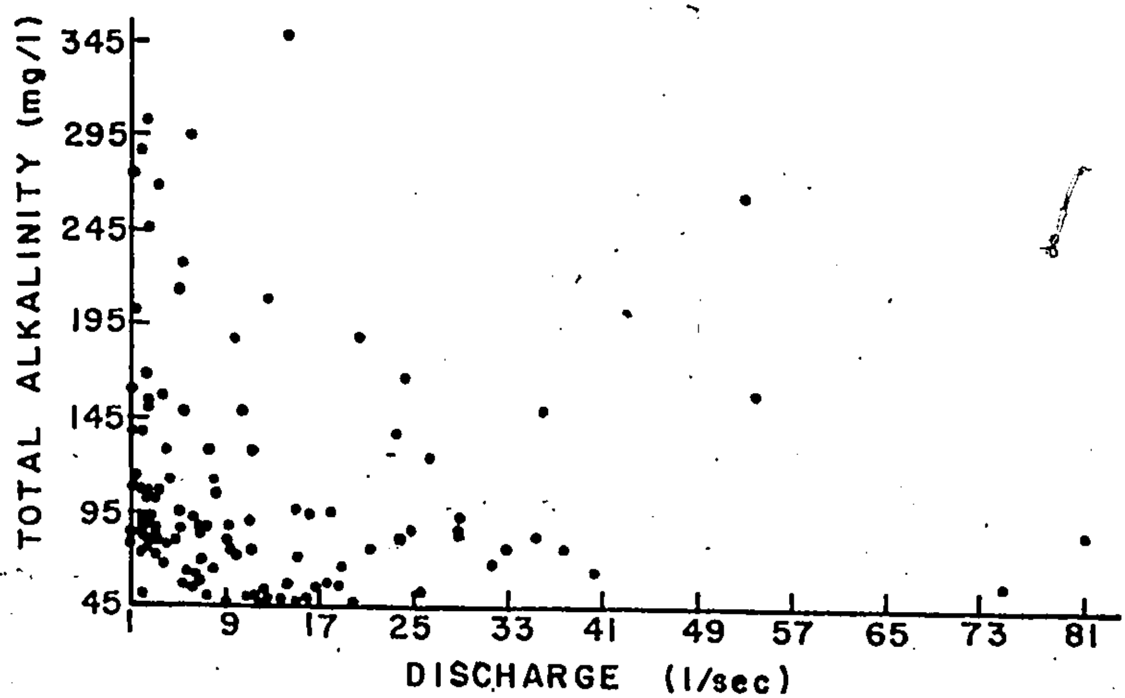


FIG. 5-9(b). DILUTION PHENOMENA, CLASS (2).

Chapter VI

COMPARISON OF RESULTS WITH SINGH'S STUDY

One of the primary objectives of this study is comparison of it to M.M. Singh's [7] study of runoff from a middle to upper middle class residential area in Windsor. His area is in the final stages of development. Singh's analyses were similar to those in this study, his samples were taken on a two hour time interval.

The average annual constituents concentrations and loadings from Singh's study are tabulated in Table 6-1 and compared with data from this study. Excluding colour, which is a subjective test, and turbidity, which was determined in a different manner for each study, it is observed that constituent concentrations were higher in Singh's study for all constituents except VSS, BOD, and total alkalinity. However TSS, BOD and total alkalinity loadings between the two studies do not bear the same relationships as their respective average concentrations. This difference in loadings occurs mainly

Table 6-1

Comparison of Annual Average Concentrations and Loading With Singh's [7] Data

	Concentrations (1) From Singh	Concentrations (1) This Study	Loadings (2) From Singh	Loadings (2) This Study
BOD	12	20.5	24.7	23.1
Total Coliform, (#/100 ml) x 10^{-3}	2400	64.0	--	--
Fecal Coliform, (#/100 ml) x 10^{-2}	88	82.0	--	--
TSS	305	279.0	493.0	610.0
VSS	59	112.0	--	201.0
Ammonia, as N	0.087	0.0540	--	0.067
Nitrate, as N	1.40	1.16	2.95	1.26
Nitrite, as N	0.090	0.0660	0.246	0.078
Orthophosphates	0.980	0.4370	8.93	0.651
Chlorides	110	72.0	164.0	75.4
Sulfates	106	46.0	186.0	38.8
Phenolphthalein Alkalinity, as $CaCO_3$	0	0.0	0.0	0.0
Total Alkalinity, as $CaCO_3$	106	115.0	223.0	140.0
Calcium Hardness, as $CaCO_3$	144	100.0	223.0	107.0
Total Hardness, as $CaCO_3$	211	151.0	304.0	147.0
pH (3)	7.35	7.40	--	--
Colour, unit	220	160.0	--	--
Turbidity, JTU	134	363.0	--	--
Sp. Conductance, milli-mhos/cm.	0.58	0.352	--	--

(1) Concentrations in mg/ℓ except where noted and for pH.
(2) Loadings in kg./ha.
(3) Arithmetic averages.

because different runoff coefficients were used (see section 4.2.2). One average annual coefficient was used in this study, whereas Singh calculated individual seasonal coefficients for which the winter coefficient was 2.5 times larger than the next largest season's runoff coefficient and 6 times greater than the smallest season's coefficient. Because of this, winter concentrations were most heavily emphasized in determining seasonal loadings. For this reason, it is deemed better to discuss average concentration values between the two studies. Seasonal average concentration values from Singh are tabulated in Table 6-2. This is to be compared with Table 5-1.

In Singh's study area most of the construction of homes has been in the past 3 to 5 years, in fact, at the time of this writing there is on-going construction of a few residences; also, landscaping and grass planting is continuing. A bus line runs on one of the streets which drained into the sewer sampled by Singh.

As one would expect and indeed was found in an urban stormwater runoff study in Tulsa [26], the better the environmental state of a neighbourhood, the lesser amounts of suspended solids, COD and coliform bacteria occurred in runoff. However, in this situation, the obverse is true. Using such

Table 6-2

Average Seasonal and Annual Constituents' Concentrations from Singh [7]

Constituent	Winter	Spring	Summer	Fall	Annual
BOD, mg/ℓ	9	8.0	16.0	16	12.0
Total Coliform (#/100 ml) x 10^{-3}	260	5700.0	3000.0	630	2400.0
Fecal Coliform (#/100 ml) x 10^{-2}	230	110.0	4.9	1.6	88.0
TSS, mg/ℓ	94	741.0	297.0	86	305.0
VSS, mg/ℓ	39	90.0	47.0	22.	59.0
Ammonia as N, mg/ℓ	0.075	0.134	0.115	0.025	0.087
Nitrate as N, mg/ℓ	1.33	2.64	0 .82	0.81	1.40
Nitrite as N, mg/ℓ	0.060	0.110	0.16	0.04	0.09
Orthophosphates, mg/ℓ	1.42	1.94	0.32	0.24	0.98
Chlorides, mg/ℓ	345	27	33	36	110
Sulfates, mg/ℓ	100	64	97	165	106
Total Alkalinity as $CaCO_3$, mg/ℓ	90	100	125	110	106
Calcium Hardness as $CaCO_3$, mg/ℓ	138	110	136	190	144
Total Hardness as $CaCO_3$, mg/ℓ	199	146	205	292	211
pH	7.22	7.43	7.45	7.39	7.35
Colour, unit	134	419	177	151	220
Turbidity, JTU	76	249	118	91	134
Sp. Conductance, milli-mhos/cm.	1.18	0.33	0.35	0.46	0.58

AVCO [26] criteria as exterior housing quality, refuse storage, rubble accumulation and vacant lot conditions for an environmental index (rating), Singh's area receives the higher (better) index. The index must be expanded to include factors discussed below.

There was not a well developed vegetative cover over Singh's whole area, some lots having more. This and construction progressing on some lots probably accounts for much of increased suspended solids in runoff from Singh's area. With increased suspended solids from the soil, one would expect soluble minerals such as calcium, magnesium, sulfates and others to rise in concentration in runoff. Differences in mineral concentrations can also be attributed to differences in soil composition but soil characteristics were generally the same for both areas [8]. Digging for basements and sodding would, however, expose different soils to stormwater runoff. Total coliform number would be expected to rise since flora, whose common habitat is the soil, are isolated in this test. But fecal coliform densities would not necessarily rise since this test is specific for coliforms primarily associated with the intestinal tracts of man and animals.

Application rates of fertilizer in the newer area were no doubt higher to get the grass growing. This would account for higher orthophosphate and nitrogen concentrations in Singh's area. Generally, the City of Windsor does not salt streets in residential areas but salt is applied to bus routes which would be the primary source of chloride levels recorded by Singh. The salt applied on streets in Windsor is above 98 per cent NaCl [27]; therefore, other constituents of runoff would not be affected by salt application.

Volatile suspended solids and BOD are dependent upon organic content which for stormwater runoff would be influenced primarily by the density of trees (leaves and fallen limbs) and other vegetation, animal feces, grass cuttings, and garbage. The area for this study had a much higher density of grown trees and shrubs and as previously mentioned, more grass and garbage exposed to runoff. Also, the population density was higher in this study area. These would effect the higher values of VSS and BOD in this study. Ratio of VSS average concentration in Singh's study to VSS average concentration in this study was 0.56; similarly, the BOD ratio between the studies was 0.61.

Relative trends of increasing or decreasing concentrations for a constituent as the year progresses are generally the same but some differ. To specify the reasons for differences in the trends would be an exceedingly difficult and complex task. It would require for instance, comparing the intensities and occurrences of rainfall and snowfall; knowledge of the temperature and number of suitable days for outdoor activity in each month; progress in building Singh's residential area; and, other data.

It is difficult to draw reasons for differences in stormwater runoff between the two areas based on socio-economic status because of the state of development of Singh's area. The factors noted above and others, some subtle and some not so subtle, contribute to the overall complexity of the runoff process, making it more difficult to characterize the vicissitudes of this process with exactness.

Chapter VII

DISCUSSION

7.1 Comparison of This Runoff Data with That of Others

Most of the studies on urban stormwater runoff are recent. Qualitative evaluation of the constituents in runoff has usually been their primary emphasis. Their qualitative findings are listed in Table 7-1. Berend et al.'s [49] data from Israel for various constituents fall within ranges in this Table as do the data of Dunbar and Henry [55] for Toronto. The data from this study fall within the generally observed ranges in the Table. These studies cannot be considered equal. Some are much more comprehensive than others in the amount of samples, method of sampling, period of time for the study and other criteria relating to their data. But they do indicate the general concentration ranges in which the constituents can be expected to fall. These studies point out the variability of a constituent's average concentration with location. Furthermore, it must be realized that these averages deviate 500 per cent or

Table 7-1

Quality of Stormwater Runoff in Various Cities

For Table 7-1 the following abbreviations and notes apply. Nitrates (NO_3), nitrites (NO_2), ammonia (NH_3) inorganic nitrogen (Inorg. N), organic nitrogen (Org. N), and total nitrogen (Total N) are all reported as N. Orthophosphates (Ortho PO_4) and total phosphates (Total PO_4) are reported as PO_4. Sulfates (SO_4) are reported as SO_4. Chlorides (Cl) are reported as Cl. Total hardness (Tot. Hard.), total alkalinity (Tot. Alk.) and calcium hardness (Ca. Hard.) are reported as $CaCO_3$. All the preceding values are reported in mg/ℓ. Also BOD, COD, TSS, VSS, total solids (TS) and grease and oil (G. & Oil) are reported in mg/ℓ.

Total coliforms (Tot. Col.), fecal coliforms (Fec. Col.) and fecal streptococci (Fec. Strep.) are all reported as (# x 10^{-3})/100 ml. Turbidity is reported in JTU. Colour is reported in colour units. Specific conductance (Sp. Cond.) is reported in millimhos/cm. pH is reported as $-\log_{10} H^+$; the arithmetic averages of pH are reported.

The following notes apply: a. 50% of samples exceeded this value. b. minimum geometric means. c. median values d. geometric mean e. values for rainfall only (snowmelt excluded).

Table 7-1 Continued

Constituent	Windsor, This Study	Windsor, After (7)	Cincinnati, After (28), (29)	Oxhey, England, After (31)	Ottawa, After (33)	Seattle, After (34)	Stockholm, After (35)	Durham, N. C., After (36)	Tulsa, After (26)	Washington, D.C., After (25)	Lubbock, Texas After (69)	Detroit, After (37)	Lawrence Kans., After (38)[e]	Ann Arbor, After (30), (32)
BOD	20.5	12	17	7	21	10	13	14.5	11.8	19	25			28
COD			111					179	85.5	335				
Tot. Col.	64	2400	58[a]			4.4			87[d]	600		61		120[b]
Fec. Col.	8.2	8.8	10.9[a]					30	0.42[d]	310				7.4[b]
Fec. Strep.			20.5[a]						6[d]	21				12[b]
NO_3	1.16	1.40			1.3	1.55					<3			1.5
NO_2	0.066	0.09			0.16									
NH_3	0.054	0.087												1.0
Inorg. N	1.28	1.58	1.0											
Org. N			2.1			2.07			0.85					1.0
Total N			3.1				1.5			2.1				
Ortho PO_4	0.437	0.98			1.2	0.22			1.15					0.8
Total PO_4			1.1			0.67	0.26	1.78		1.3				5.0
SO_4	46.0	106			94									
Cl	72	110	12				168	7.6	11.5				21	
TS					384			2730	545	2106	900		1180	
TSS	279	305	227	194	150		122		367	1697	530	193	974	2080
VSS	112	59	57				80			145	145	102		218
Turbidity	363	134	176			230								
Colour	160	220	87			90[c]								
pH	7.40	7.35	7.5						7.4	6.5	7.4		7.7	
Sp. Cond.	0.35	0.58							0.108					
Tot. Alk.	115	106									93			
Tot. Hard.	151	211	81											
Ca. Hard.	100	144												
G. & Oil	18.7				19	67	47							

more from the extreme values in most cases.

Expected average qualitative values from the data in Table 7-1 for those constituents are listed in Table 7-2. The chloride value in Table 7-2 would be most subject to change depending on the use of salt for street de-icing in the winter. Its value was chosen assuming the city to be northern and does salt its major streets for snowfall. Consideration of other local factors such as nearness of heavily trafficked roads or industries would have some modifying influence on values in Table 7-2 but for large residential-light commercial areas the deviations would not be that great. One of the reasons for the very high total solids concentration in Durham, N.C. was expressway construction [36]. In Tulsa, open drainage ditches sampled there lend themselves to higher pollutant concentrations [26]. Studies lasting one year or more generally indicate suspended solids averages to be in the range 200 - 400 mg/ℓ.

Other substances of interest that have been identified or measured in urban stormwater runoff are as follows: phenols by Burm _et al._ [30] and Benzie and Courchaine [39]; lead by Söderlund and Lehtinen [34], Bryan [36], [41] and Söderlund _et al._ [40]; pesticides by Weibel _et al._ [42] and Bryan [36], [41]; and Salmonellae by Geldreich _et al._ [43].

Table 7-2

Predicted Average Quality of Urban Runoff for a Residential-Light Commercial Area

	Concentration
BOD, mg/ℓ	15
COD, mg/ℓ	150
Total Coliform[a], (#/100 ml) x 10^{-3}	200
Fecal Coliform[a], (#/100 ml) x 10^{-3}	12
Fecal Coliform[a] (#/100 ml) x 10^{-3}	15
NO_3, mg/ℓ N	1.3
NO_2, mg/ℓ N	0.10
NH_3, mg/ℓ N	0.08
ORGANIC N, mg/ℓ	1.5
ORTHO PO_4, mg/ℓ	0.80
TOTAL PO_4, mg/ℓ	1.6
SO_4, mg/ℓ	90
CHLORIDES, mg/ℓ	80
TSS, mg/ℓ	300
VSS, mg/ℓ	100
Turbidity, JTU	200
Colour, unit	150
pH[a]	7.4
Specific Conductance, milli mhos/cm	0.30
Total Alkalinity, mg/ℓ as $CaCO_3$	90
Total Hardness, mg/ℓ as $CaCO_3$	150
Grease and Oil, mg/ℓ	30

a - arithmetic means

7.1.1 Variation of Urban Stormwater Runoff Quality with Time

Most authors have found that concentration of any runoff constituent except pH generally decreases as the storm progresses. Reference to Table 5-2 shows that the preceding observation is true of this study also. It is further noted that the ratio of fecal coliforms to total coliforms decreased with time during a storm. Bacterial numbers were higher in the earlier stage of a storm but their counts exhibited quite wide fluctuations as the storm progressed. Orthophosphates, VSS and pH concentrations did not change significantly with time. However, there is one important exception to the above: suspended solids vary with discharge or intensity of rainfall. Singh [7], Weibel et al. [29] and others [35] reported this. A look through Appendix A confirms that TSS rose and fell with discharge. There remains a general tendency for TSS to decrease with time. Volatile SS usually follows the rise and fall of TSS but to a markedly lesser degree. Total SS and VSS were not found to follow any dilution phenomena in Chapter V.

Biochemical oxygen demand also exhibited a tendency to increase with a secondary period of increased rainfall intensity, for example, in the storms of Oct. 22-23, Mar. 10-11 and, to a lesser extent, on Jun. 26. In many storms the shape of the BOD curve is similar to the TSS curve. It is suggested that increased rainfall intensity would be able to move more matter (increased TSS usually effects increased VSS); also the resultant increase in discharge would more effectively scour the sewers.

All runoff constituents in almost every storm were noted to increase when the discharge fell below about 0.28 ℓ/sec. (o.01 cfs.). These concentration values when discharge is low are probably somewhat high due to location of the sampler inlet head near the bottom of the sewer. A higher proportion of matter on the sewer bottom was sucked into the sampler. Dry weather flows did still have higher concentrations of constituents than when runoff occurred. Other samples, not listed in this work, taken up to ten hours after runoff subsided confirmed this.

7.1.2 Other Influences on the Quality of a Storm

Greater length of the antecedent dry weather period was declared by Wilkinson [31] and Warnock [33] to increase BOD concentrations for a storm. To check this phenomenon, the average BOD of each storm was compared with the average BOD for storms in the season in which it occurred. The length of the antecedent dry weather period was noted. An antecedent dry weather period of two to three days was found necessary to raise BOD concentrations above average. Other constituents were examined in this manner. Total SS exhibited a slight tendency to increase with length of the dry weather period but the other constituents were random in their behaviour. The Chicago group [54] found that dirt and grit on streets usually increased rather than decreased after a storm. For a preceding dry weather period of less than one day for a storm, it's average concentrations of all constituents were in most cases below their seasonal averages.

The AVCO group [26] generated some equations to predict concentration of particular components of urban runoff. Their best equations for total coliform, fecal coliform and BOD were

$$\text{LOG (total coliform)} = 5.2598 - 0.0853(Z_1) - 0.9638(Z_2) - 0.08297(Z_3)$$

$$\text{LOG (fecal coliform)} = 1.5072 - 0.0039(Z_4) - 0.6503(Z_3) + 12.341(Z_5)$$

$$\text{LOG(BOD)} = 2.7531 + 0.0086(Z_1) - 0.6484(Z_2) - 0.3674(Z_3)$$

where Z_1 = time since start of rainfall
Z_2 = antecedent amount of rainfall (in.) in the storm under consideration
Z_3 = amount of last previous rainfall (in.) of 0.10 in. or more
Z_4 = time (hr.) since last previous rainfall of 0.10 in. or more
Z_5 = average intensity (in./hr.) of last previous rainfall
Total coliform is in thousands/100 ml., fecal coliform in number/100 ml and BOD in mg/ℓ

The data from seven storms were put in these equations to predict their hourly values but the results were not in agreement with observed values. The Z-factors influence and others such as the rainfall intensity immediately before a sample was taken and the intensity average of all preceding precipitation in a storm should be further researched for data in this study.

7.2 Discussion of Seasonal Runoff Quality

The seasonal variation of urban runoff quality generally reflects seasonal storm characteristics and seasonal activities of man in a northern climate. In winter, due to street de-icing, chloride concentrations are very high; both coliform counts are lowest due to winter's low temperatures less conducive to their survival; and, TSS are lower due to snowfall and less intensive rainfall. BOD is lowest in winter - vegetation is dormant and outdoor activities are curtailed.

In spring orthophosphates attain their highest value, probably a reflection of lawn fertilization. The inorganic forms of nitrogen rise above winter values and remain at about the same levels for spring, summer and fall. High rainfall intensities in spring raised TSS concentrations to their highest average values.

Coliforms counts became exceedingly high in the summer when temperatures were optimal for their survival. Outdoor activities of man and animals are most frequent in the summer months. The BOD's were highest because of the reasons in the preceding statements and the increased productivity of grass and vegetation. TSS values remain high due to frequent, short, intense showers.

In the fall longer, less intense rainfalls drop TSS averages considerably to their lowest values. BOD concentrations fall as the weather cools. Some snowfall and consequent street de-icing near the end of fall begins to raise chloride concentrations.

7.3 Annual and Seasonal Loadings of Stormwater Runoff

Loadings from this study are compared with those from others in Table 7-3. Although not directly reported by the Tulsa group [26], TSS loading would be approximately 712 kg./ha./yr. (635 lb./acre/yr.) if one assumed the ratio of TSS to TS for storm quality (which was reported) remains the same for loadings. In the Tulsa study, two out of four industrial areas were higher in loadings than the average residential-light commercial area, the others lower. They concluded that increased usage of an industrial or commercial area decreased pollution because of increased maintenance of the area.

The average seasonal loadings for this study are listed in Table 5-3. Spring contributes the highest loadings of all seasons excepting chlorides and coliform counts. It is also the season with the largest amount of rainfall (Table 3-7). In the Tulsa study [26] it was alleged that the season with the highest amount of

Table 7-3

Loadings of Urban Stormwater Runoff from Various Cities

(In kg./ha./yr.)[d]

Constituent	Windsor, Sept. 1972-Aug. '73; This study	Windsor, Jan. 1971-Dec. '71 After Singh (7)	Cincinnati, Jul. 1962-Jul. '64; After Weibel et al. (29)	Oxhey, England, April 1953-Mar. '54; After Wilkinson (31)	Tulsa, Sept. 1969-Aug. '70; After AVCO (26)[c]	Stockholm, Sweden, Jan. 1969-'71; After Söderlund and Lehtinen (35)[c]	Durham, N. C., May 1969-Feb. '70; After Bryan (36)	Ann Arbor, Mich., June 1965-Aug. '65; After Burm et al. (30)
BOD	24.1	25	43	4.8	29	43	94	35
COD			355		219		1166	
NO_3 - N	1.26	2.95						0.9
NO_2 - N	0.078	0.245						
NH_3 - N	0.067					1.8		0.8
Inorganic N	1.405							
Organic N					2.1			0.4
Total N			12.9			3.45		
Ortho PO_4	0.651	8.92			2.4			1.0
Total PO_4			3.8			0.49	3.8	3.1
SO_4	38.8	186						
Chlorides	75.4	164					49	
TSS	609.9	493	968[b]	103		620		1132
VSS	198.4		179[b]			490		207
TS					1058		17823	
Total Alkalinity[a]	139.5	223						
Total Hardness[a]	146.7	304						
Calcium Hardness[a]	106.5	223						
Grease and Oil	20.1					2.4		

a. As $CaCO_3$. b. After Weibel et. al. (24) for July 1962- Sept. 1963. c. Only residential and commercial areas considered. d. Except for Ann Arbor study which is in kg./ha. for June, July, and August only.

*multiply by 0.892 for lb./acre/yr.

rainfall contributed the most pollutants. This conclusion applies here. It is interesting to note that quoted annual precipitation in Oxhey, England [31] was less than in Windsor while annual precipitation in Cincinnati [29], Tulsa [26] and Durham [36] was greater than that in Windsor and the corresponding loadings for these cities (Table 7-3) are also generally greater or lesser as their annual precipitation compared to Windsor. Comparing loads of TSS, BOD, nitrates, orthophosphates and total hardness for storms which had a greater amount of precipitation than 2.0 cm. (0.79 in.) against the average loads per storm, the trend of higher amounts of loading with higher amounts of rainfall is visible. The data is given in Table 7-4.

The loadings represent more truly and accurately than concentration, the harm done to a receiving body of water. Comparing quality of BOD for Windsor, Durham, N.C. and Stockholm from Table 7-1, one could easily misconceive the loadings for these particular cities in Table 7-3.

7.3.1 Hourly Loadings

The hourly loadings in Table 5-4 demonstrate clearly that all constituents except coliforms decrease in loadings as a storm progresses. The data in that table point out the first and second hours to be the

Table 7-4

Comparison of Loads of Storms of Greater Total Precipitation With Average Storm Load in kg./ha./yr.

	Loading				
Storm	TSS	BOD	NO_3	PO_4	Total Hardness
Average Storm	287	11.1	0.60	0.31	73.8
Oct. 22-23	163	24.8	1.16	0.43	120
Dec. 12-13	235	22.9	0.64	0.39	144
Mar. 10-11	567	7.8	0.70	0.47	100
Mar. 16-17	549	---	1.32	0.24	194
Jun. 26	942	27.3	1.05	0.63	100
July 26	532	15.2	0.64	0.62	69.0

most heavily loaded. The bulk of the pollution loading is carried in the first five to seven hours of runoff from a long storm.

It was noted in Chapter V that seasonal, hourly loadings in winter and fall were more uniform than spring and summer. This reflects the nature of precipitation in the respective seasons. Winter and fall precipitation events are generally more uniform in intensity.

7.3.2 An Empirical Analysis of the Pollution Loading, Considering Treatment of Urban Stormwater Runoff

Many who have studied urban runoff have described the first flush phenomena but few have established quantitative means of estimating its extent and relation to the loading of the latter stages of a storm. The previous section documents first flush phenomena in this study.

Between 43 and 50 per cent of the BOD and TSS were discharged in the first 29 per cent of the total volume of runoff, Wilkinson [31] reported. Friedland et al. [3] in establishing quantitative criteria for mass emission rates asserted that an equation of the form below was best.

$$Y = a/(b + i)$$

where Y is in kg./ha.-cm.; i is cm. of runoff due to the storm; and, a and b are adjustable constants depending on the constituent.

The product Y · i gives the net mass emission per storm. This form of equation seems generally good, however, for BOD and TSS a term should be included in the numerator, reflecting the precipitation intensity or possibly the variation in precipitation intensity with time.

Computation Procedure

For this study the amount of load of each constituent that was contained in a period of incremental volume (e.g. load of TSS contained in first $40m^3$ of runoff for each storm, load contained in second $40m^3$ of runoff for each storm, etc.) was summed for all storms and expressed as a percentage of its total load for the year. The storms of Oct. 21, Nov. 25-26 and Jan. 23-24 were not used in this computation for reasons discussed in section 5.4. All samples with discharge less than 0.28 ℓ/sec. (0.01 cfs.) were deleted as discussed in sections 5.3 and 7.1.1. An hour for which no sample was taken was assumed to have constituent concentrations that were an average of constituent concentrations from samples on either side of the missing hour. Loads were assumed to equally distributed throughout an hour's discharge.

Example: Discharge for first hour of storm = 10 ℓ/sec. = 0.10 m^3/sec.
BOD concentration = 20 mg./ℓ
Incremental Runoff Volume = $40m^3$
Total load in first hour = .72 kg.
Total runoff volume in first hour = $360m^3$
BOD load in incremental runoff volume =.08 kg.

Results and Discussion

The results for most constituents are shown in Figs. 7-1(a) and (b). Study of these curves demonstrates that pollutional loading is greater in the earlier stages of storms by about 10 per cent compared to the volume of runoff passed. Regression analyses were performed on the curves. The best predicted equations relate the per cent of total constituent load to per cent of total runoff volume (P_v) and are listed below.

% of Total Coliform loading = $3.25\ P_v^{.76}$, % of Fecal Coliform loading = $5.40\ P_v^{0.65}$.

% of TSS loading = $1.36\ P_v^{.94}$, % of VSS loading = $1.51\ P_v^{.92}$.

% of BOD loading = $1.95\ P_v^{.87}$, % of NH_3 loading = $4.67\ P_v^{.68}$.

% of NO_3 loading = $3.14\ P_v^{.75}$, % of NO_2 loading = $4.38\ P_v^{.69}$.

% of Ortho PO_4 loading = $1.91\ P_v^{.87}$, % of SO_4 loading = $3.06\ P_v^{.76}$.

% of Chlorides loading = $5.10\ P_v^{.66}$, % of Total Alkalinity Loading = $2.85\ P_v^{.78}$.

% of Total Hardness loading = $2.76\ P_v^{.78}$, % of Calcium Hardness loading = $2.07\ P_v^{.84}$.

Statistics for the Log-Log lines of the above equations were as follows: all intercept and slope terms were different from zero at a 0.1% significance level or better; all Pearson product-moment correlation coefficients were greater than 0.977; all F-values

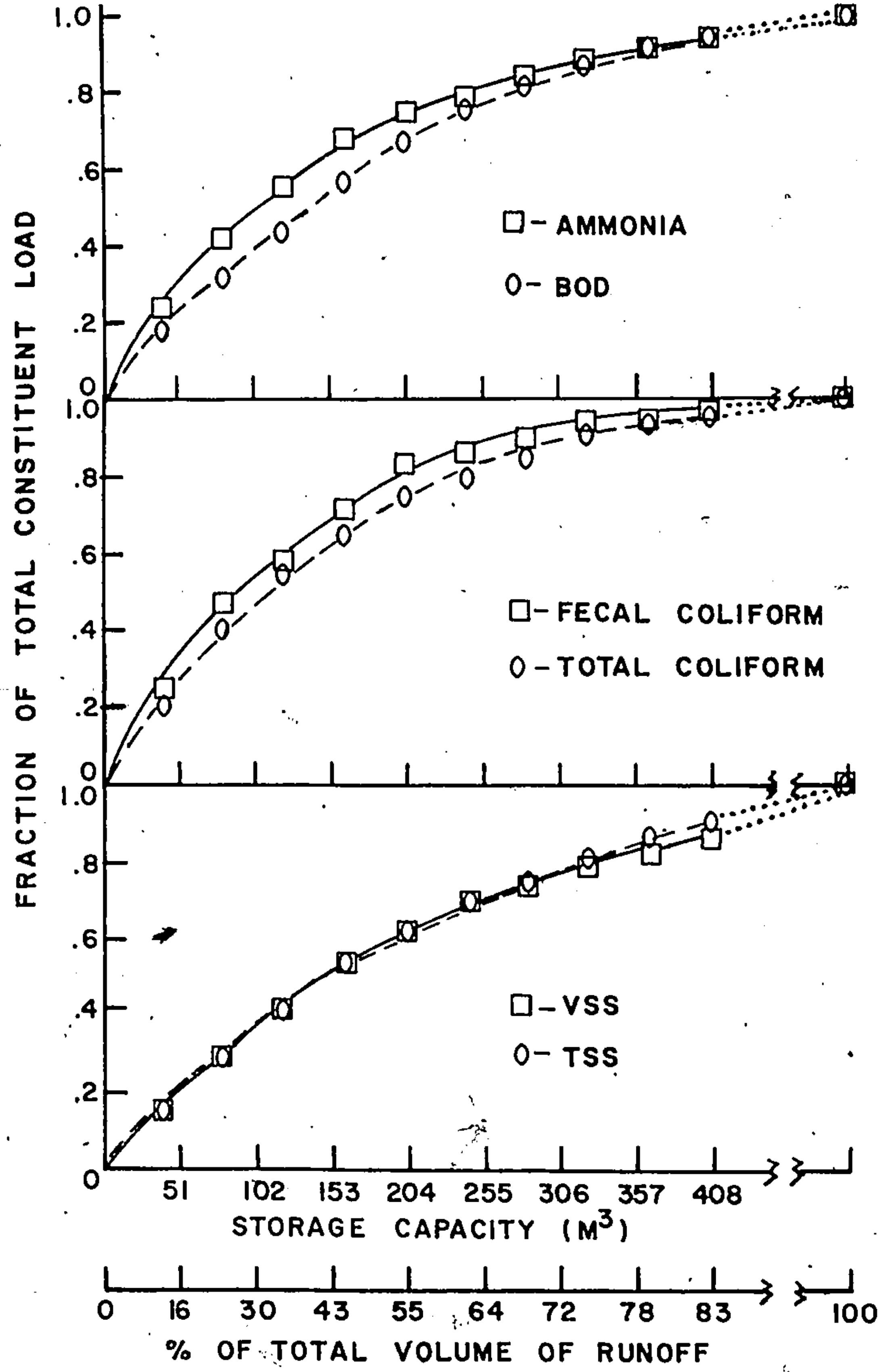


FIG. 7-1(a). LOADINGS CONTAINED IN INCREMENTAL VOLUMES OF RUNOFF.

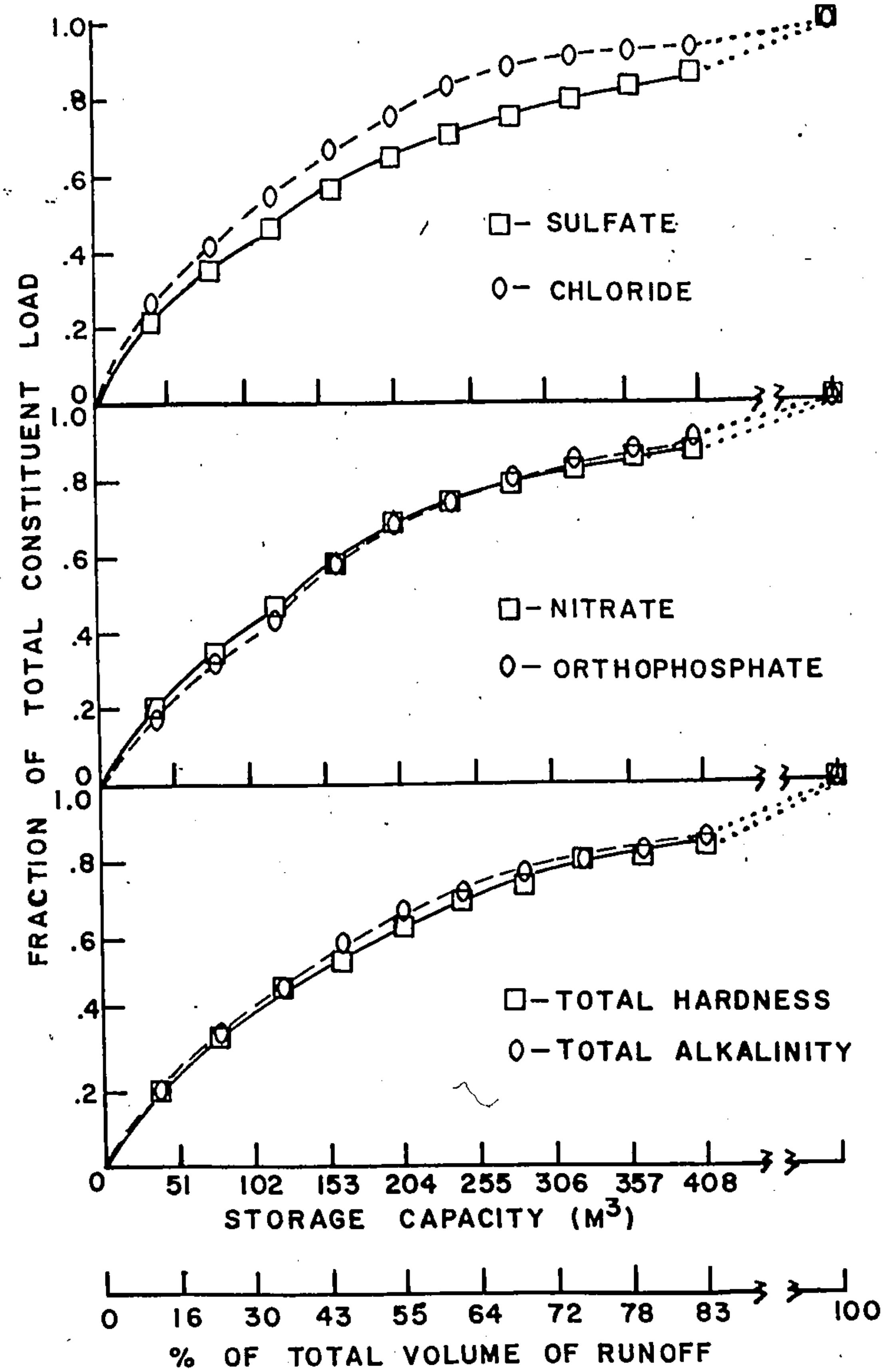


FIG. 7-1(b). LOADINGS CONTAINED IN INCREMENTAL VOLUMES OF RUNOFF.

were greater than 300 at a 0.01% significance level; and, the coefficient of variation was less than 1.9% for each equation.

Besides correlating well with the per cent of runoff passed the constituents correlated well among themselves (Pearson product-moment correlation coefficients were above 0.98). An average equation generated for all the constituents plotted against the per cent of volume of runoff passed was

$$\% \text{ of constituent loading} = 2.83\ P_V^{.78}$$

where F-value = 5763 at 0.01% significance value, Pearson product-moment correlation coefficient = 0.980.

There results can be generalized for the City of Windsor or any city. If pollutional loadings are higher or lower but the runoff loading follows the same pattern as in this study, only the total annual loading needs to be changed. Differences in the amount of runoff per cm. of rainfall can be adjusted similarly to total load changes.

The area of the City of Windsor (1971) is 11,980 ha. (46.24 mi.^{2}) [56]. Since the runoff coefficient computed for this study was low (Sec. 4.2.2) a rational method runoff coefficient (Eq. 4.3) equal to 0.40 which is in the range recommended by the ASCE [14] will be assumed for the city. It is reasonable to assume that runoff from the test drainage area that was not intercepted by the storm drain sampled was similar in composition to that which was intercepted and sampled. The average runoff of the City of Windsor will be assumed to have a similar makeup to that from the test drainage area. Windsor's annual precipitation is 83.59 cm. (32.91 in.) from Table 3-7. Therefore, the annual runoff is 33.44 cm. (13.16 in.). The volume of annual runoff is then 4.006×10^7 m^3 (1.415×10^9 ft.^{3}). For example, if Windsor built treatment facilities capable of handling

$$\frac{.40}{.171}\ (245\text{m}^3)\ \frac{11{,}980 \text{ ha.}}{11.94 \text{ ha.}} = 5.57 \times 10^5 \text{ m}^3$$

where the rational runoff coefficient is 0.171 from this study, 245m^3 is from Figs. 7-1(a) and (b) and the test drainage site area is 11.94 ha. from this study.

Windsor would subject at least 70 per cent and in some cases 80 per cent of the storm runoff pollutional load to treatment. This capacity is less than 1.4 per cent of the total amount of annual runoff. Care must be used in determining the average number of storms per year and the amount of precipitation per storm to determine the per cent of volume of runoff that will be captured at a given treatment capacity.

Some other aspects of load treatment capabilities (Figs. 7-1(a) and (b)) must be mentioned. These figures are for annual averages. The first few incremental volumes of runoff in winter and fall contain less amount of loads than the same first incremental volumes of runoff in spring and summer. Therefore, loadings subjected to treatment will not be relatively as high in winter and fall as in spring and summer.

The Cincinnati group [29] and Evans et al. [4] found that short period removal times for BOD and particularly SS were not adequate. Evans et al. further reported that utilizing plain settling, about four hours treatment time was needed to effect maximum removal of SS, VSS, COD, BOD, organic nitrogen and total phosphates. If batch settling basins were used for treatment with four hours detention time, some storms of longer duration would have two or more segments of the storm subjected to treatment. For instance, if treatment capacity was 245 m^3 (8640 ft^3) for this residential area sampled, for the storm of Oct. 22-23 the basin would have filled after ten hours of rainfall but runoff lasted 27 hours. After 14 hours the basin would have been emptied and more runoff would then be subjected to treatment. The curves in Figs. 7-1(a) and (b) are somewhat conservative.

Finally, treatment should be adjusted for the particular loadings of a season in accordance with Table 5-3. Also, seasonal demands of the receiving body of water or user of the runoff would have to be considered.

7.3.3 Comparison of Pollutional Loadings of Stormwater Runoff and Sanitary Sewage

Singh [7] has determined sanitary sewage loadings for BOD, TSS and orthophosphate for a residential area in Windsor with population of 38,700. These loadings are compared with those from this study in Table 7-5.

Table 7-5

Comparison of Annual Stormwater Runoff and Sanitary Sewage Loadings in kg./ha./yr.*

	(1) Runoff	(2) Sanitary Sewage	Percentage Ratio of (1) to (2)
TSS	610	317	192.4
Orthophosphates	.651	25.3	2.6
BOD	24.1	337	7.2

*multiply by 0.89 for lb./acre/yr.

But Palmer's study [15] indicated that it only rains more than 0.076 cm. (0.03 in.) per hour, 3 per cent of the time in Detroit. Assuming the same rainfall distribution in Windsor, being next to Detroit, the whole stormwater pollution load is delivered in very short periods of time which magnifies runoff loading importance. Weibel *et al.* [29] expressed the stormwater runoff load discharge rates during the periods of time of runoff only as percentages of average raw sewage loads as follows: SS - 2,400%; COD - 520%; BOD - 110%; total hydrolyzable PO_4 - 70% and total nitrogen - 200%.

Stormwater runoffs should be compared to the effluent of sanitary sewage treatment plants. Fair et al. [16] state as a general rule that with secondary treatment of sanitary sewage the effluent would be expected to have BOD in the range of 10 to 20 mg/ℓ and suspended solids less than 30 mg/ℓ. The high suspended solids content and other loads of stormwater runoff and the fact that these loads are discharged in short bursts make it more reasonable to treat stormwater runoff than provide tertiary treatment.

7.4 Discussion of the Individual Constituents

Windsor's urban runoff enters the Detroit River which provides 90 per cent of the water entering the notorious Lake Erie [57]. Beeton [9] concludes that "...the important changes in the Great Lakes are those taking place in the sediments because of the tremendous amounts of allocthonous materials entering the Lakes." He further states that most fish in the Great Lakes are part of the benthos during a critical period in their life histories. The benthos of the Lakes is becoming oxygen depleted, Lake Erie sediments having an oxygen demand 10 times that of Lake Huron and about 3 times that of Lake Michigan. Some further pollution aspects of the individual constituents and their behaviour will be examined.

The high colour values probably reflect the high suspended solids load of runoff more than anything else. Singh [7] found good agreement between colour and turbidity. Stormwater runoff pH levels are generally near 7.00 and present no special difficulties.

7.4.1 Total and Fecal Coliform

There were 228 known outbreaks of disease or poisoning during 1946-60 [58]. Stormwater runoff could be a vehicle for transmission in some of the cases. Van Donsel *et al.'s* studies [59] with survival of indicator bacteria in soil indicate that the fecal coliform group is the more significant group relating to the sanitary history of a drainage area.

In this study the annual ratio of fecal to total coliform was 0.132, ranging from 0.125 in summer to 0.416 in winter. The ratio of fecal to total coliform decreases as runoff progresses. Bacteriological quality exhibited the widest variation of any constituent. Seasonal temperature has the most important effects on bacteriological quality.

7.4.2 Specific Conductance and Chlorides

In section (5.5.1) it was established that specific conductance depends primarily upon the presence of chlorides and calcium hardness, with chlorides usually being more important. From a measurement of specific conductance and either chlorides or calcium hardness the other can be estimated. Since chlorides are more important in correlating with specific conductance, it would seem advisable to measure calcium hardness and specific conductance to determine chlorides from the equation. Specific conductance and chlorides are subject to dilution phenomena in runoff.

Increasing salt concentrations in bodies of water have imposed meromictic conditions on Irondequoit Bay, New York [60] and First Sister Lake in Michigan [61]. The resulting density stratification maintained anaerobic conditions in the benthos. With increased use of salt from winter road de-icing this is more of a problem. The Chicago group [54] reported that 100 per cent of salt applied to streets appeared in stormwater runoff from Feb. 24 to April 1, 1967 although they noted other previous studies had found only one-half of the salt applied was discharged in runoff.

The City of Windsor applied about 14,000 tons of salt in the winter of 1973-74 (information courtesy of Dept. of Roads and Sewers). Snowfall was 114 cm. (45 in.) compared to an annual average of 104 cm. (41 in.). Even if only one-half of this reaches Lake Erie it is still a considerable load. Oronby and Kee [62] have shown that even though Lake Erie displaces its whole volume every 2.6 years, it would take approximately ten years to cleanse itself of chlorides, with only a small input of chlorides.

7.4.3 Total and Calcium Hardness, Total Alkalinity and Sulfates

The four above are all subject to dilution phenomena. The annual ratio of calcium hardness to total hardness was 0.73, the fall ratio was 0.59 while the ratio in the remaining seasons was between 0.73 and 0.79. The statistics for the relation between calcium and total hardness were good. Only one test need be made to determine the other.

The relation developed for sulfates and total hardness was likewise quite acceptable. The annual ratio of sulfates to total hardness was 0.26, the seasonal ratios were very close to this value.

Total hardness also exhibited a good relationship to total alkalinity except in spring. Total hardness could then be measured to estimate calcium hardness, sulfates and total alkalinity except in spring when a separate alkalinity measurement may have to be made. The deviation of alkalinity from the total hardness correlation in spring is not understood at this time, further study should be undertaken. These minerals would be expected to have fairly constant relationships since their primary source is the soil. However, fertilizer and lime application would influence them to a degree.

These four constituents have not been singled out frequently as primary factors in eutrophication studies although carbon has been sometimes put forth as a limiting substance. However, they do have significance in treatment and/or industrial use of runoff.

7.4.4 BOD, TSS, VSS, Turbidity

Turbidity measurements can facilitate estimation of TSS using the equation in section 5.5.4. The annual ratio of VSS to TSS was 0.33, the seasonal ratios were within 0.07 of this value. The VSS values may be high due to loss of weight of clay upon ignition. Suspended solids are the heaviest loading in stormwater runoff, higher than values in combined sewers [25], [30] or sanitary sewage. Average TSS would probably have correlated better with discharge, if discharge at the time of sampling was used instead of average hourly discharge.

Inaba [63] found maximum BOD to usually occur somewhat earlier than TSS except when rainfall intensity was light. He also reported that maximum BOD was higher when rainfall intensity was higher. In this study, BOD peak values usually occurred at the same time as TSS peaks. Inaba sampled on two to three minute intervals. BOD values may be somewhat low. To measure full BOD of suspended solids, they should be kept in suspension. An increase in rainfall intensity increases TSS concentration and the BOD contained therein as noted earlier. Buildup of SS decreases the volume of lakes, covers the lake bottoms and increases the costs of dredging. The harm done by BOD to streams and lakes is well understood.

7.4.5 Phosphorous and Nitrogen

None of the nitrogen components or orthophosphates correlated well with the other constituents examined. Nitrogen in urban runoff was estimated to contribute 4.5 per cent of all sources of N to U.S. stream waters [64]. The same group [64] estimated urban runoff to contribute somewhat less than 5.8 per cent of phosphorous to U.S. waters. Weibel [28] estimated urban runoff to contribute about 3.9 per cent of phosphorous to Lake Erie. Phosphorous is generally regarded as the limiting nutrient for increasing the trophic level of a lake [45], [47] although there is some controversy over this. Phosphates in urban stormwater runoff do not represent high percentages of sanitary sewage loads. Even if 90 per cent of orthophosphates in Windsor are removed, runoff orthophosphate levels would still be equivalent to the sanitary effluent. But nitrogen and phosphorous levels in runoff are above Sawyer's index [45] for nuisance algal blooms in lakes.

Chapter VIII

FINDINGS AND CONCLUSIONS

8.1 Findings in This Study

1. The average annual and seasonal quality of urban stormwater runoff for an homogeneous residential area in Windsor is tabulated in Table 5-1.

2. The average annual and seasonal loadings for the above area are tabulated in Table 5-3.

3. A first flush phenomena is evident for all constituents measured. All constituents except pH generally decreased as runoff progressed.

4. The following are subject to dilution phenomena in runoff: total and calcium hardness, specific conductance, nitrates, nitrites, sulfates, chlorides and total and fecal coliform; and to a lesser extent total alkalinity, orthophosphates and ammonia are subject to the phenomenon.

5. The per cent of a constituent's total yearly load contained in an incremental volume of the yearly runoff is shown in Figures 7-1(a) and (b).

6. A rational runoff coefficient (defined as $\left(\frac{\text{Volume of runoff from the area}}{\text{Volume of rainfall over the area}}\right)$ of 0.171 was found for the area.

7. Pollution loading of fall and winter storms is more uniform through out the period of a storm than for a storm occurring

in spring and summer.

8.2 Conclusions from the Research

1. Urban stormwater runoff is not a suitable diluent for sanitary sewage and itself makes a significant contribution to pollution of waters.

2. Determination of the quality of stormwater runoff depends upon the constituent, season of the year, makeup of the soil, rainfall intensity, variation of rainfall intensity with time, the environmental quality and vegetation cover of the drainage area and length of the antecedent dry weather period.

3. The environmental rating of a drainage area should consider the use of the area, state of houses and buildings, conditions of vacant lots, uncontrolled rubbish, the amount of vegetation cover and loose dirt.

4. It is concluded that average quality of runoff from a residential-light commercial area will be as shown in Table 7-2.

5. It is concluded for this area that winter and fall are more uniform in loadings as runoff proceeds because rainfall intensities are more uniform in these seasons.

6. The season with the most rainfall, spring in this case, contributes the highest loads of pollution except for chlorides and coliforms. Storms with larger amounts of precipitation contribute higher loads.

7. The best regression equations among and between the constituents are listed in Table 8-1.

8. The regression equations for per cent of constituent total

Table 8-1

Best Regression Equations Among The Constituents of Runoff

1. [a] Specific Conductance = 0.0089 + 0.0015 $[Cl^-]$ + 0.0023 $[Ca^{++}$ Hardness]

2. [a] $[Ca^{++}$ Hardness] = 31.1 + .50 [Total Hardness]

3. [a] $[SO_4^{++}]$ = .29 [Total Hardness]

4. [a,b] [Total Alkalinity] = 12.9 + .63 [Total Hardness]

5. Turbidity (JTU) = 84.1 + .71 [TSS]

6. [d,e] Fecal Coliform = -7339 + 0.151 (Total Coliform)

a. Hardness is in mg/l as $CaCO_3$. b. equation applies to all seasons except spring. c. all constituents except sp. conductance and turbidity in mg/l. d. equation applies to summer only e. coliform in #/100 ml.

annual loading contained in an incremental volume of total yearly runoff are in section 7.3.2. The general equation describing all constituents is

$$\% \text{ of constituent loading} = 2.83 P_v^{.78}.$$

where P_v is the per cent of total annual runoff.

9. Total suspended solids did not correlate well with any constituent (except turbidity) or with average hourly discharge. It is concluded that it is affected by rainfall intensity.

10. BOD did not correlate well with any constituent or group of constituents. It is concluded that an antecedent dry weather period of 2-3 days will raise BOD's above average and that higher rainfall intensity increases BOD concentrations. BOD peak values occur near peak TSS values.

11. The three forms of inorganic nitrogen or orthophosphate did not correlate well with any single constituent or average hourly discharge.

12. It is concluded that treatment of urban stormwater runoff should be implemented before tertiary treatment of sanitary sewage.

13. The minerals from the soil, sulfates, calcium and total hardness and total alkalinity, remain fairly constant relative to each other throughout the year in runoff except for total alkalinity in spring.

14. Loadings reflect more accurately the nature of runoff than does quality.

Chapter IX

RECOMMENDATIONS FOR FURTHER RESEARCH

1) A comparable study should be performed on a stable industrial and an upper class residential area in Windsor.

2) The accuracy of grab samples should be checked by study with continuous samples and if possible continuous monitoring of constituents during stormwater runoff.

3) Second and higher order quality relations among the constituents in stormwater runoff should be statistically examined.

4) Further research should be done on the data to find predictive models of quality and loadings including amount of precipitation, intensity of precipitation, intensity and amount of antecedent precipitation in a storm before a sample was taken, length of the preceding dry weather period and the amount and intensity of precipitation of the first preceding storm.

5) Further research into treatment and uses of storm water runoff needs to be performed.

APPENDIX A

PLOTS OF DISCHARGE, RAINFALL AND CONSTITUENTS FOR EACH STORM

The following notes and abbreviations apply to the graphs in this appendix.

At the top of each graph is noted the date of the storm. Nitrates, nitrites and ammonia values are plotted as N. Orthophosphate is abbreviated to PO_4. Total hardness (Tot. Hard.), calcium hardness (Ca. Hard.) and total alkalinity (Tot. Alk.) are as $CaCO_3$. BOD, TSS, VSS and all the preceding are in mg/ℓ. Turbidity is in JTU. Total and fecal coliforms are in #/100 ml. Rainfall is in hundredths of an inch* and discharge is in ft^3/sec.**. The value of rainfall plotted for the first hour is diminished by 0.03 in. (0.076 cm.) (see section 4.2). The times at the bottom of the page of the first plot for each storm apply to the hour immediately to the left of the time.

The precise values of all constituents in Appendix A are listed in Appendix D.

Table A-1 immediately following lists temperature and grease and oil values for the storms.

---

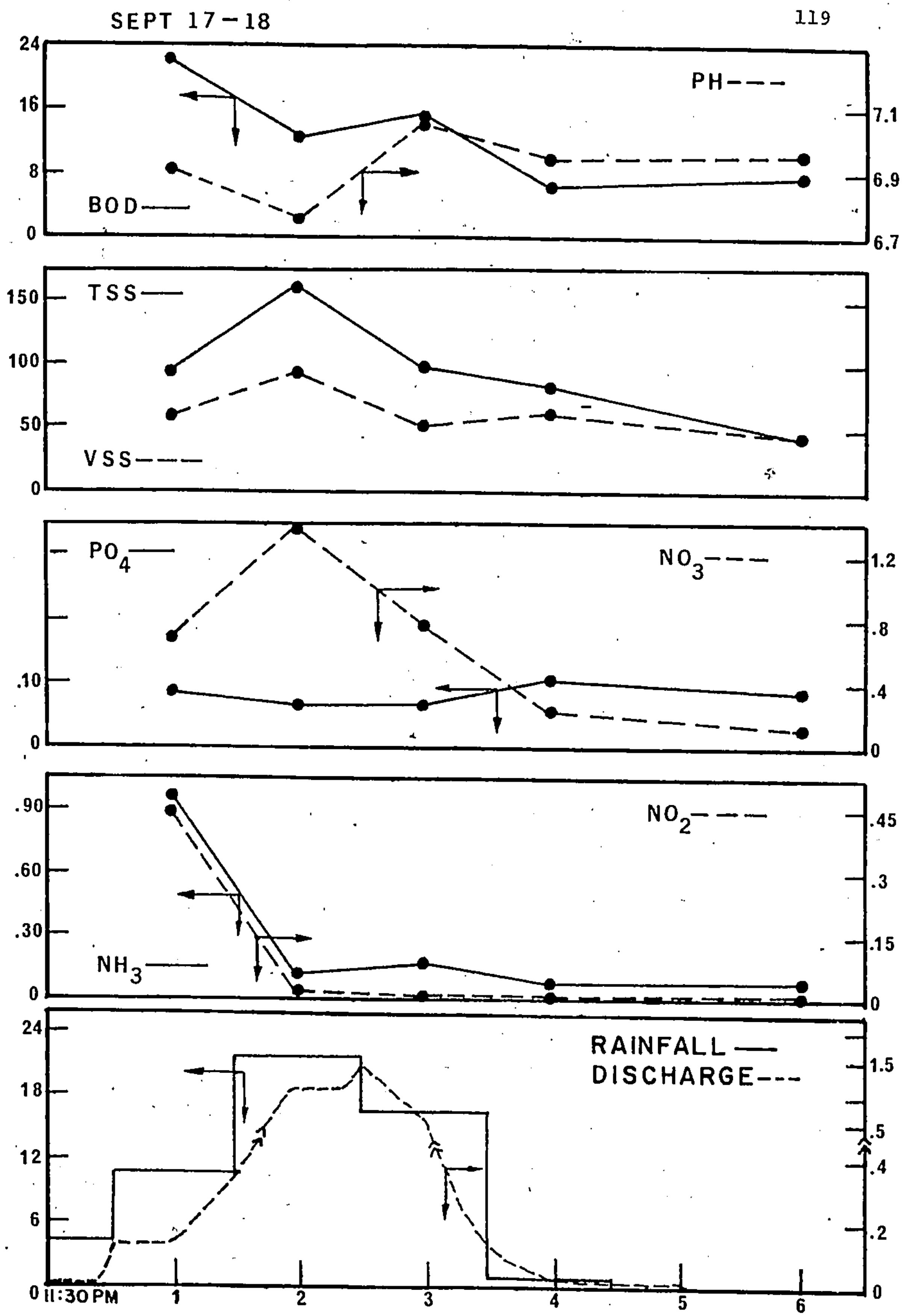
*multiply by 2.54 for cm.
**multiply by 28.3 for ℓ/sec.

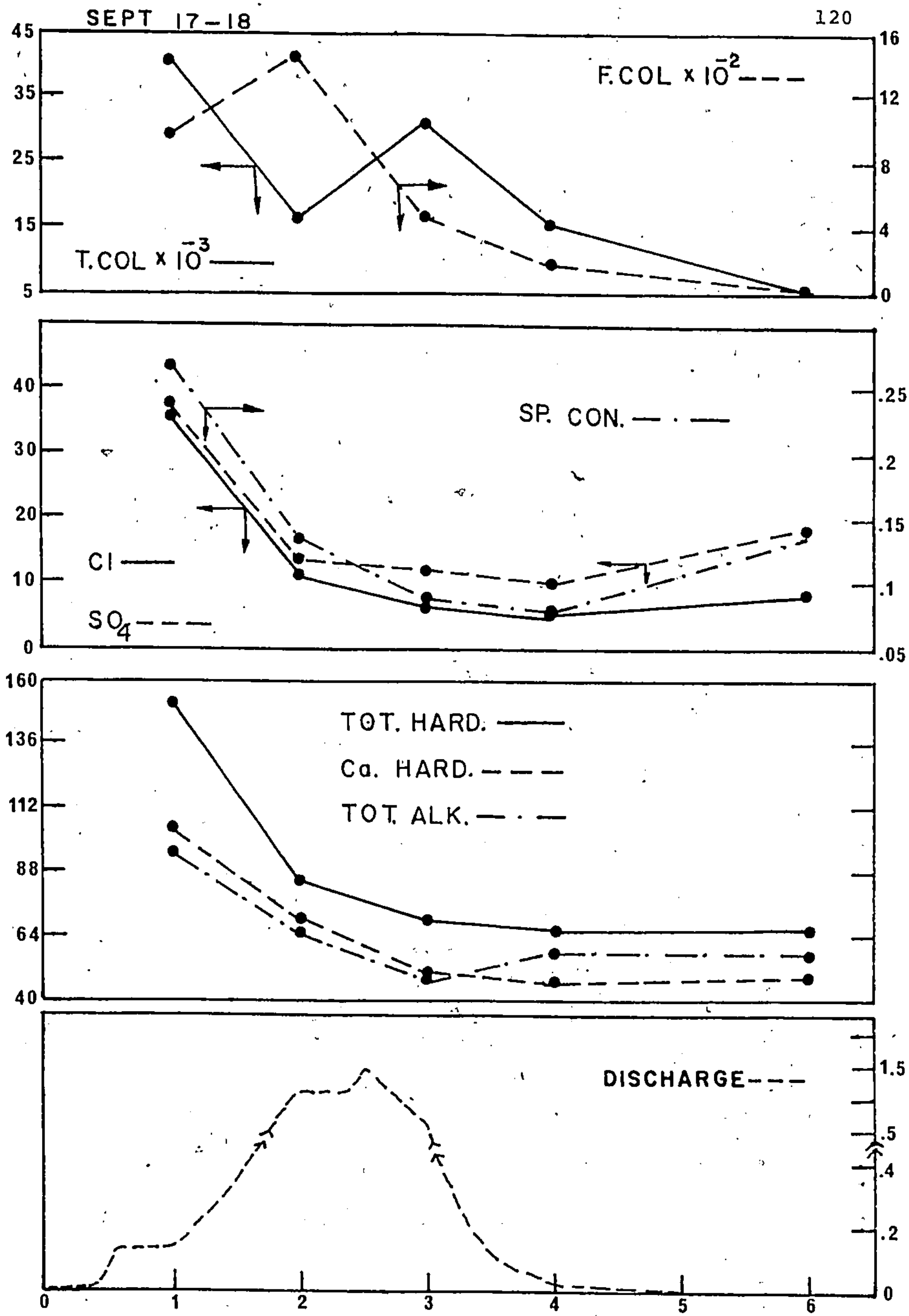
TABLE A-1

TEMPERATURE AND GREASE AND OIL DATA FOR EACH STORM

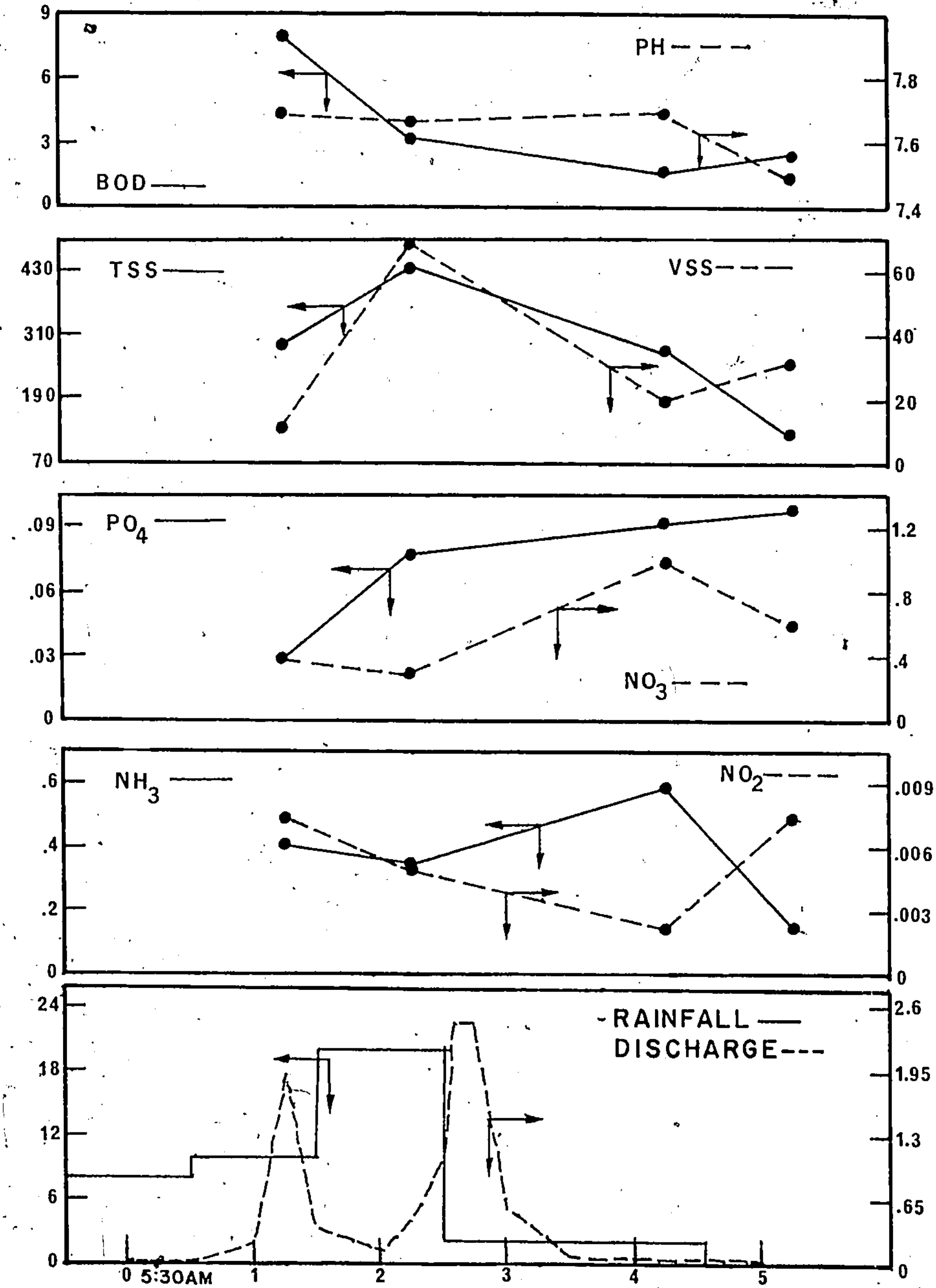
Storm No.	Date	Temperature, °C	Grease and Oil, mg/ℓ
1	Sept. 17-18, 1972	10.0	----
2	Sept. 26, 1972	11.0	34.6
3	Oct. 21, 1972	15.0	----
4	Oct. 22-23, 1972	14.0	----
5	Nov. 10-11, 1972	14.0	39.0
6	Nov. 25-26, 1972	12.0	8.9
7	Dec. 12-13, 1972	8.5	9.9
8	Jan. 3-4, 1973	7.2	11.3
9	Jan. 23-24, 1973	6.0	18.6
10	Feb. 1, 1973	6.0	17.3
11	Mar. 10-11, 1973	6.5	13.2
12	Mar. 16-17, 1973	4.0	----
13	Mar. 29, 1973	7.0	----
14	Mar. 31, 1973	7.0	----
15	Apr. 9, 1973	6.0	12.6
16	Apr. 16, 1973	7.0	23.3
17	May 7-8, 1973	10.0	15.4
18	May 8, 1973	10.0	----
19	May 27, 1973	12.0	14.3
20	June 6, 1973	15.5	23.9
21	June 26, 1973	15.5	----
22	July 10, 1973	16.5	19.2*
23	July 20, 1973	15.5	19.2*
24	July 26, 1973	18.5	----
25	July 31 - Aug. 1, 1973	18.0	----

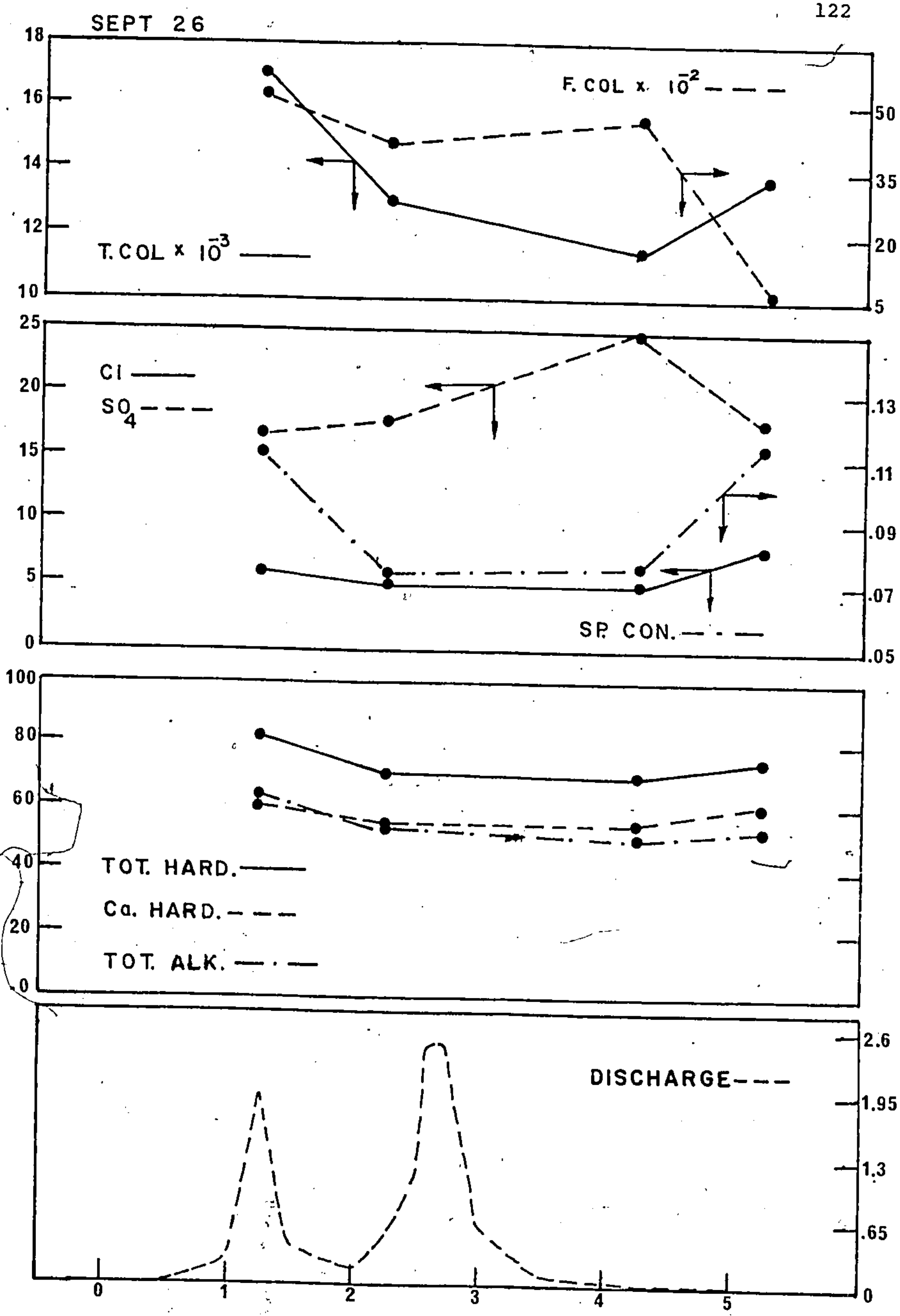
*combined sample.

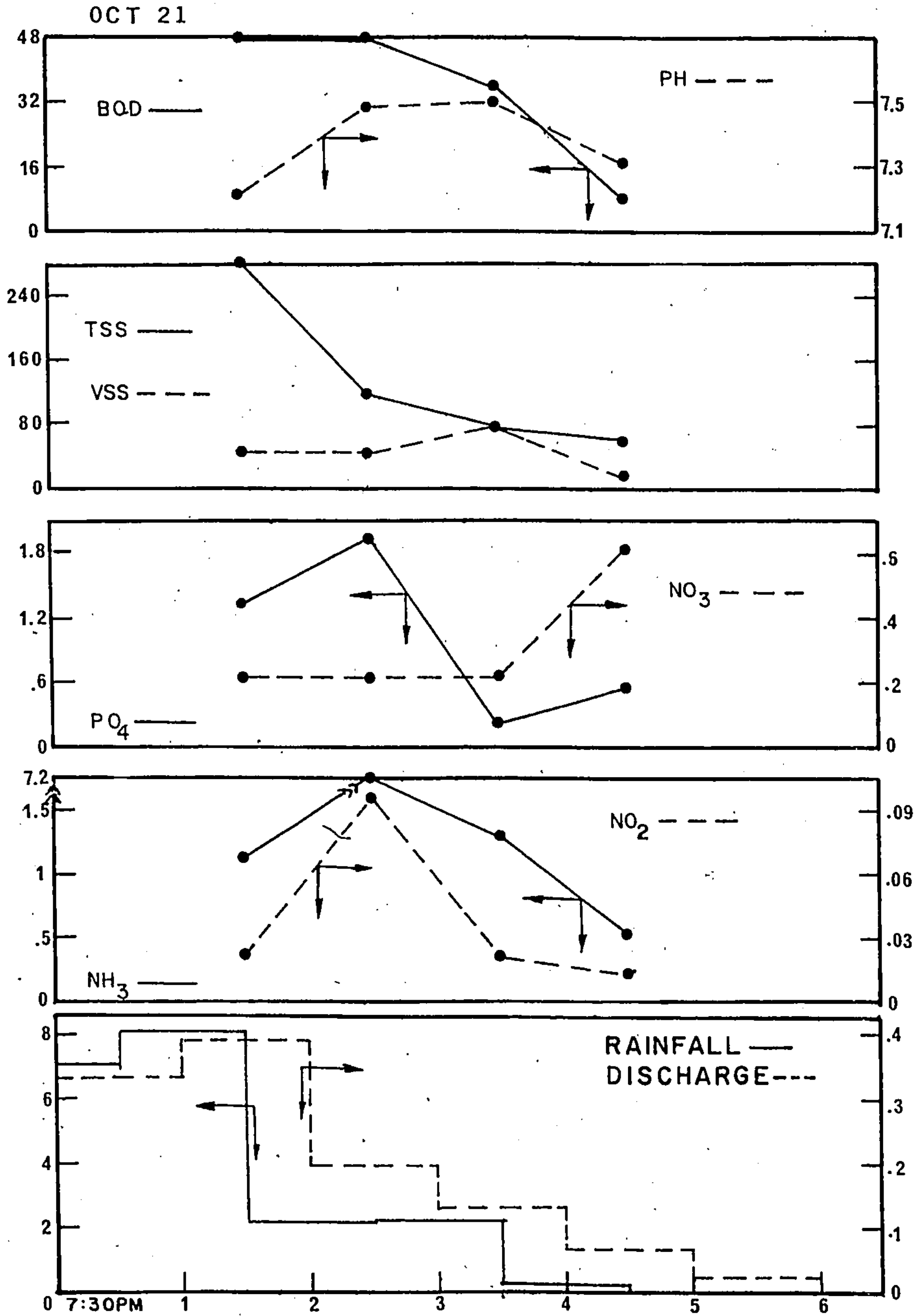

SEPT 17-18
24
16
8
0
PH
7.1
6.9
6.7
BOD
TSS
VSS
150
100
50
0
PO4
NO3
1.2
.8
.4
.10
0
0
NO2
.90
.60
.30
0
.45
.3
.15
0
NH3
RAINFALL
DISCHARGE
24
18
12
6
0
1.5
.5
.4
.2
0
11:30 PM
1
2
3
4
5
6

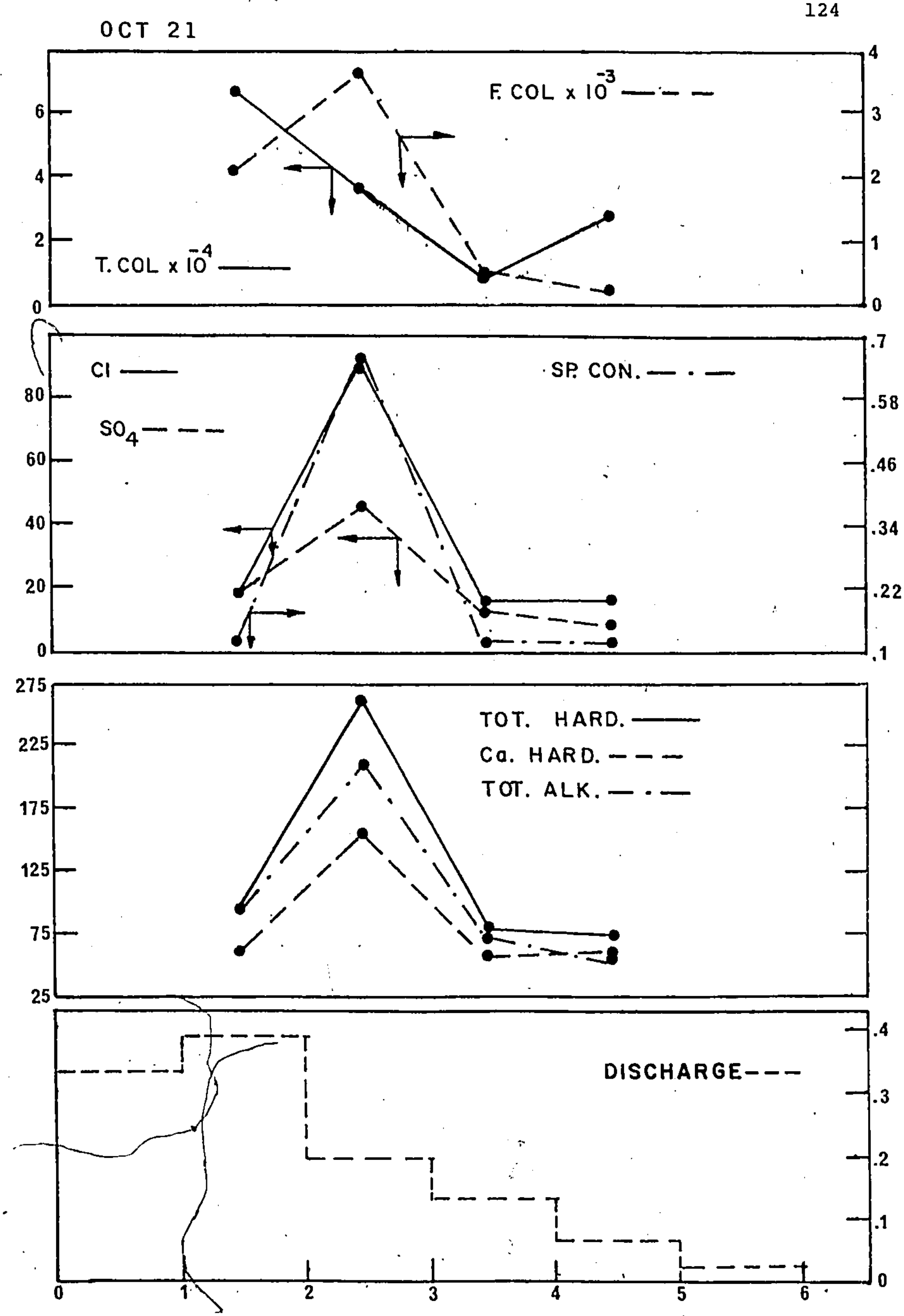

SEPT 17-18
F.COL × 10^{-2}
T.COL × 10^{-3}
SP. CON.
Cl
SO_4
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
45
35
25
15
5
16
12
8
4
0
40
30
20
10
0
.25
.2
.15
.1
.05
160
136
112
88
64
40
1.5
.5
.4
.2
0
0
1
2
3
4
5
6

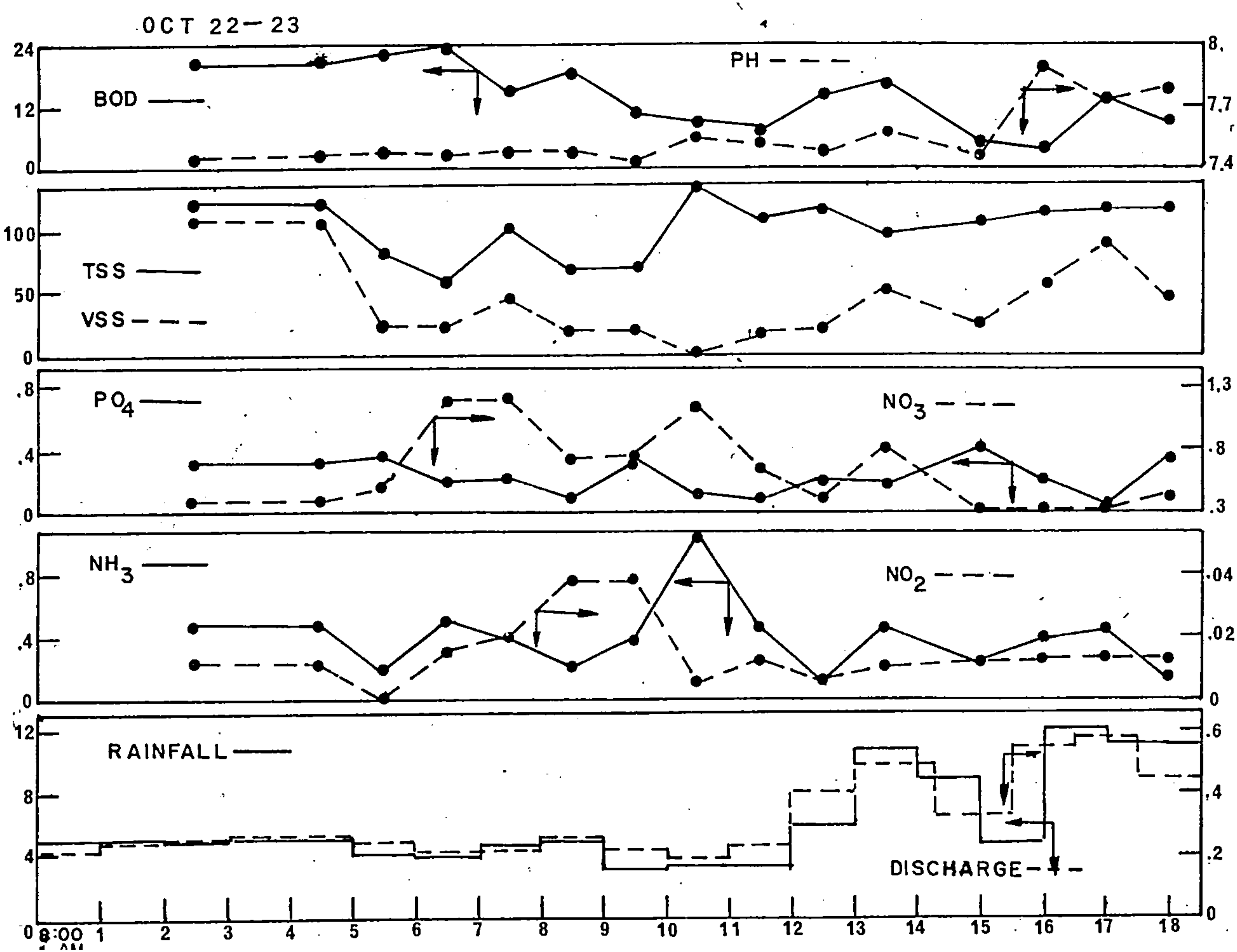
SEPT 26

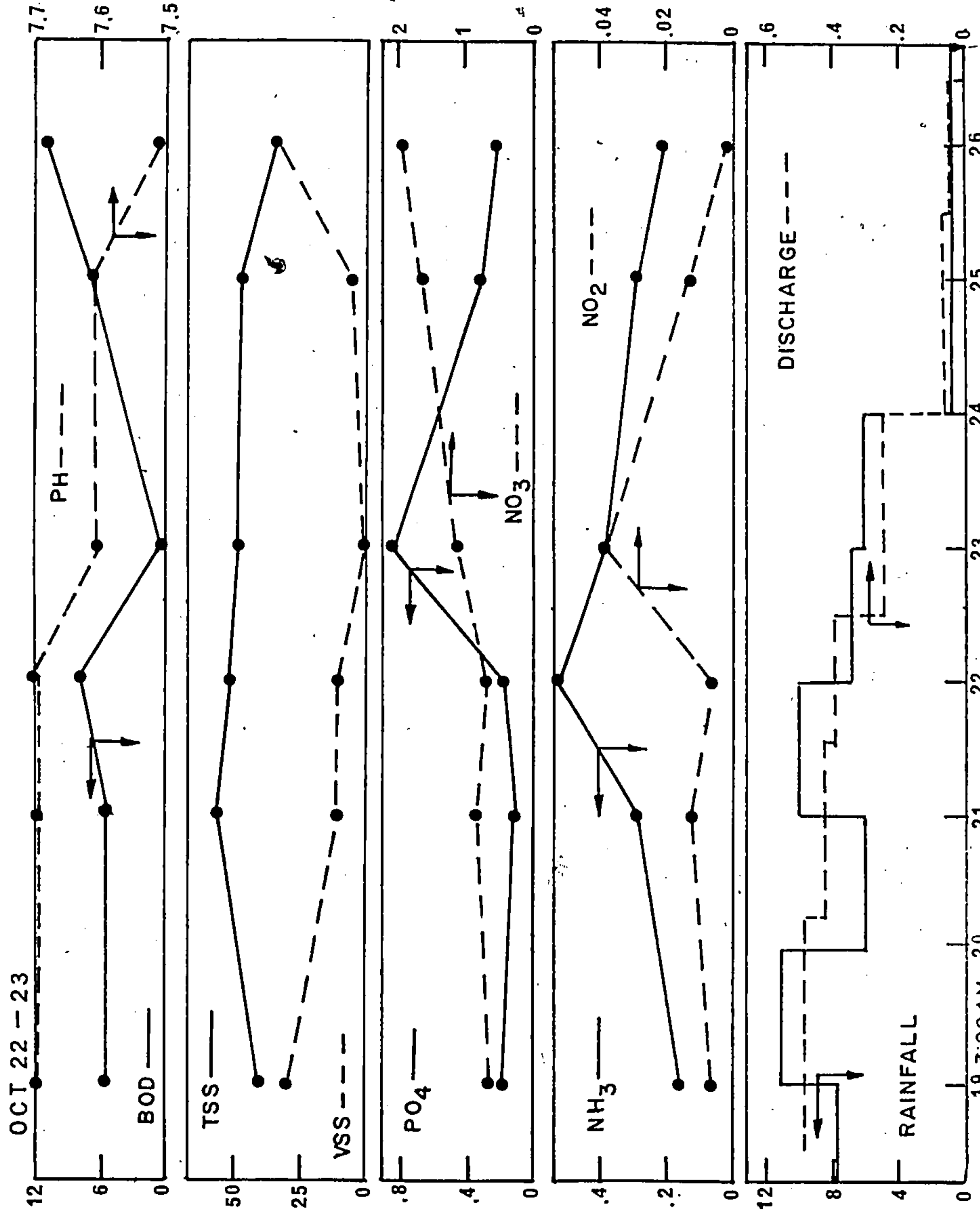

9
6
3
0
BOD
PH
7.8
7.6
7.4
430
310
190
70
TSS
VSS
60
40
20
0
.09
.06
.03
0
PO_4
NO_3
1.2
.8
.4
0
.6
.4
.2
0
NH_3
NO_2
.009
.006
.003
0
24
18
12
6
0
RAINFALL
DISCHARGE
2.6
1.95
1.3
.65
0
0 5:30AM
1
2
3
4
5

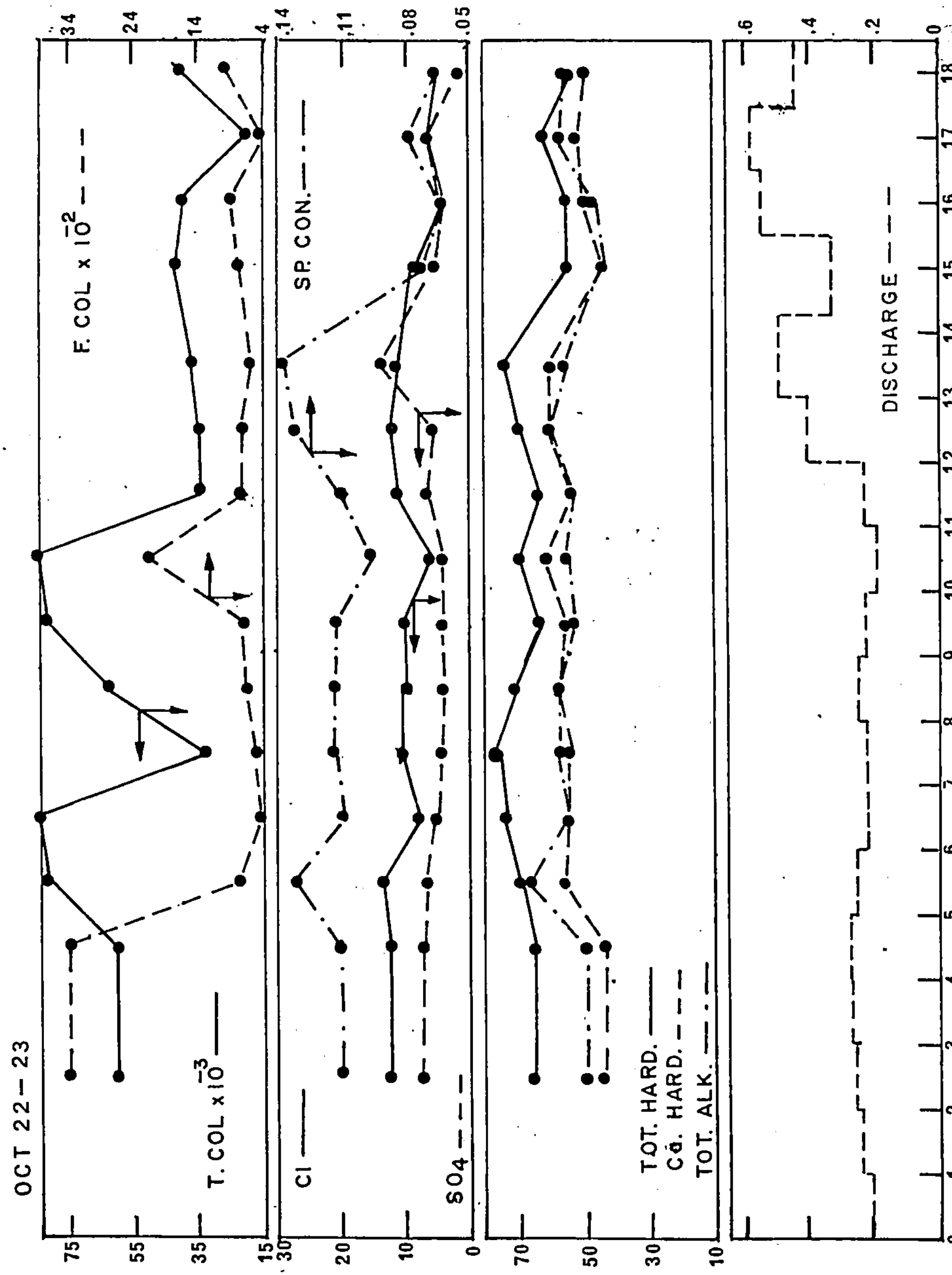

SEPT 26
F. COL x 10^{-2}
T. COL x 10^{-3}
18
16
14
12
10
50
35
20
5
Cl
SO_4
SP. CON.
25
20
15
10
5
0
.13
.11
.09
.07
.05
TOT. HARD.
Ca. HARD.
TOT. ALK.
100
80
60
40
20
0
DISCHARGE
2.6
1.95
1.3
.65
0
0
1
2
3
4
5

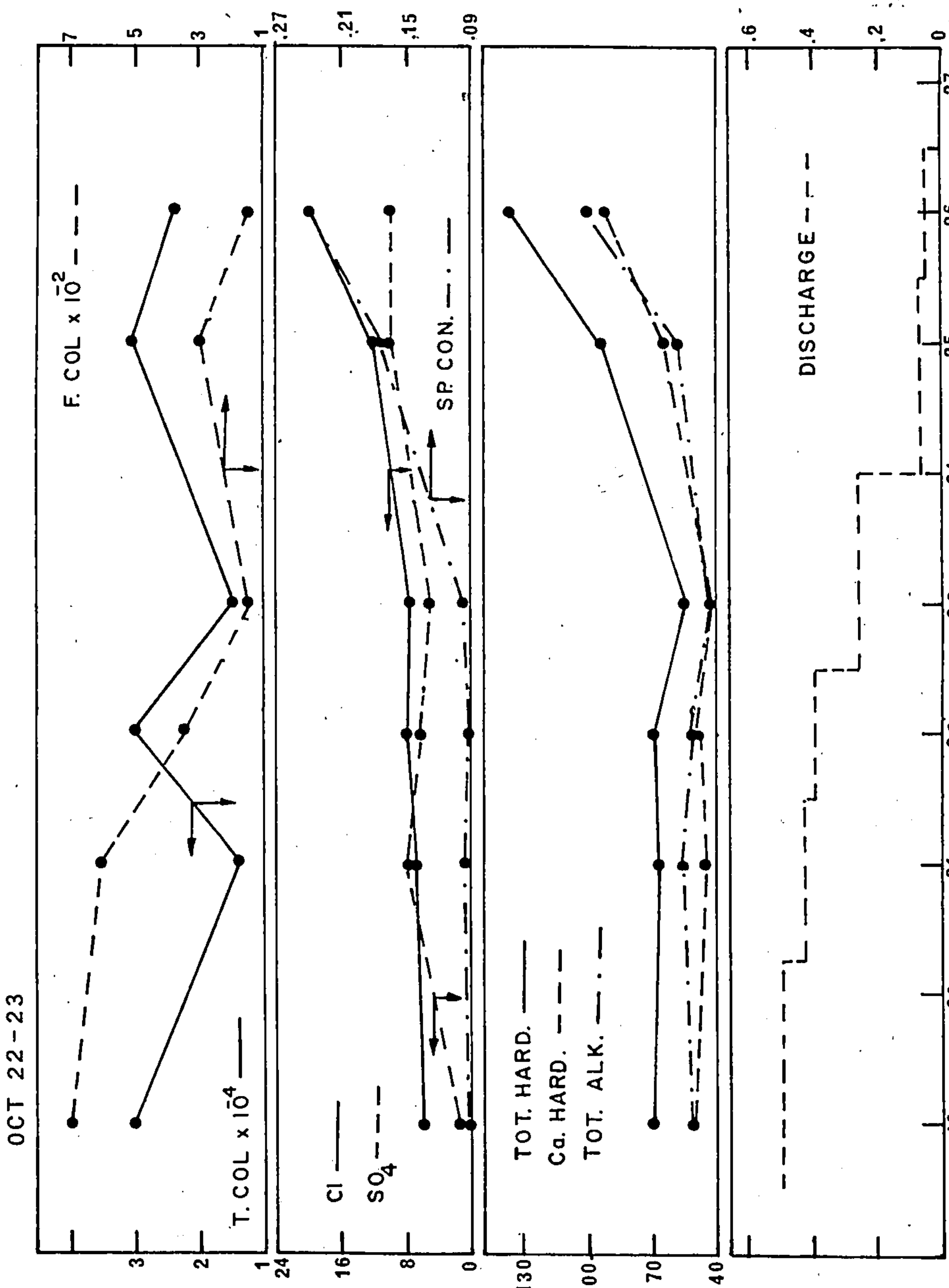

OCT 21
BOD
PH
TSS
VSS
PO_4
NO_3
NH_3
NO_2
RAINFALL
DISCHARGE
0 7:30PM
1
2
3
4
5
6

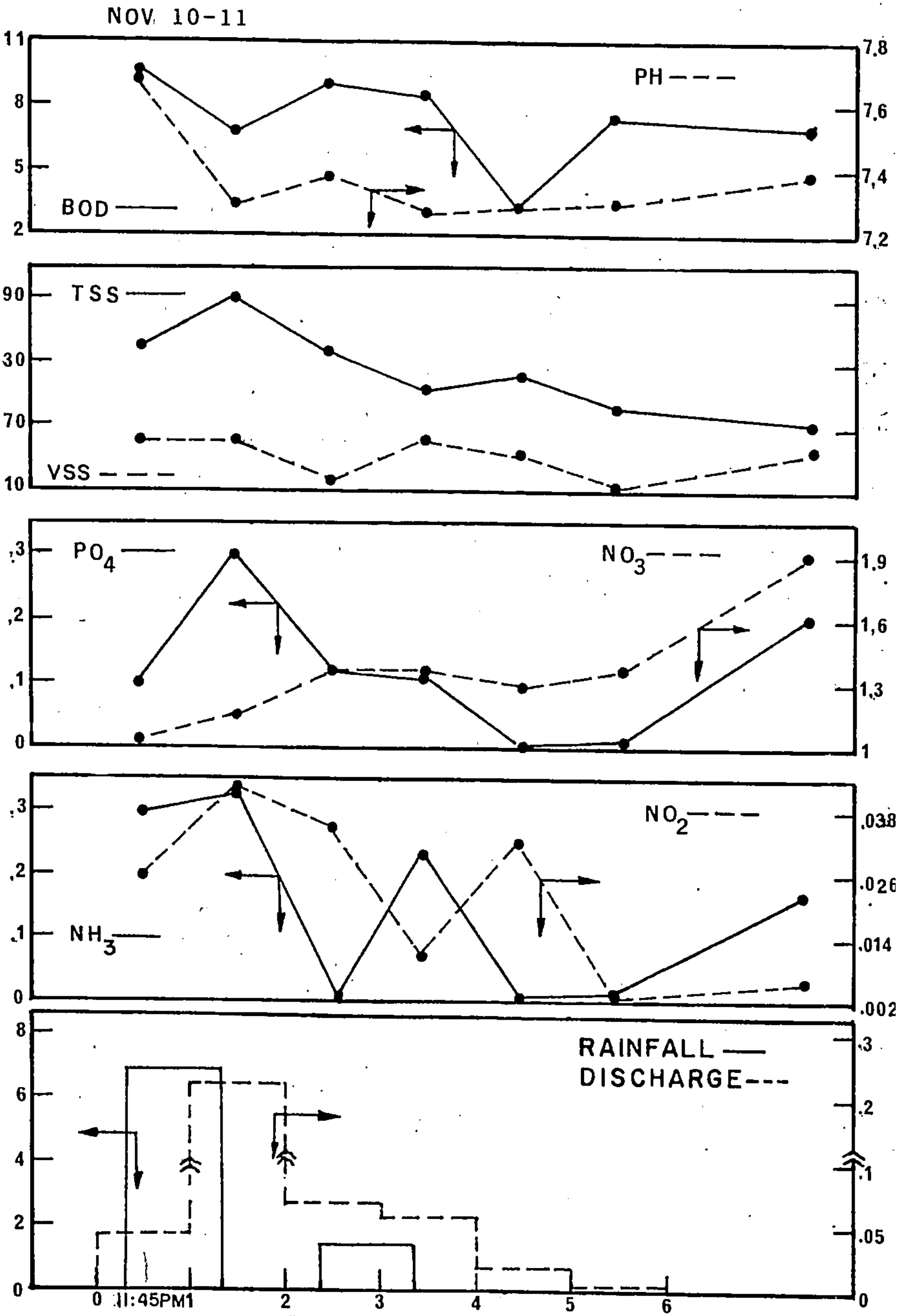

OCT 21
F. COL x 10^{-3}
T. COL x 10^{-4}
Cl
SP. CON.
SO_4
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
0
2
4
6
1
3
20
40
60
80
.7
.58
.46
.34
.22
.1
275
225
175
125
75
25
.4
.3
.2
.1
5

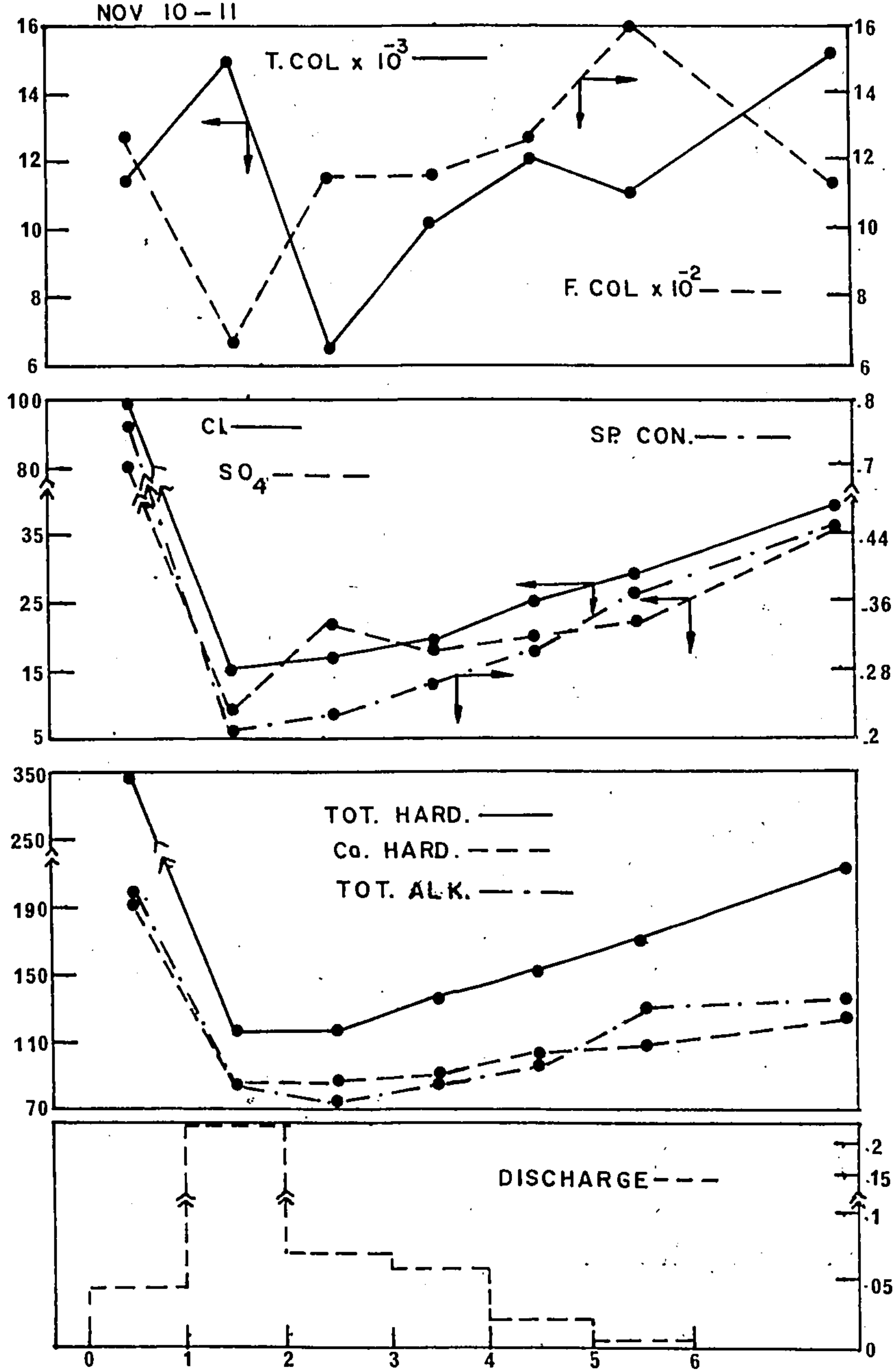

OCT 22 — 23
BOD
PH
TSS
VSS
PO4
NO3
NH3
NO2
RAINFALL
DISCHARGE
24
12
0
8.
7.7
7.4
100
50
.8
.4
1.3
.3
.04
.02
12
8
4
.6
.2
8:00
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18


OCT 22 - 23
BOD
PH
TSS
VSS
PO4
NO3
NH3
NO2
RAINFALL
DISCHARGE
19 3:00AM
20
21
22
23
24
25
26
12
6
0
7.7
7.6
7.5
50
25
0
.8
.4
0
2
1
0
.4
.2
0
.04
.02
0
12
8
4
0
.6
.4
.2
0

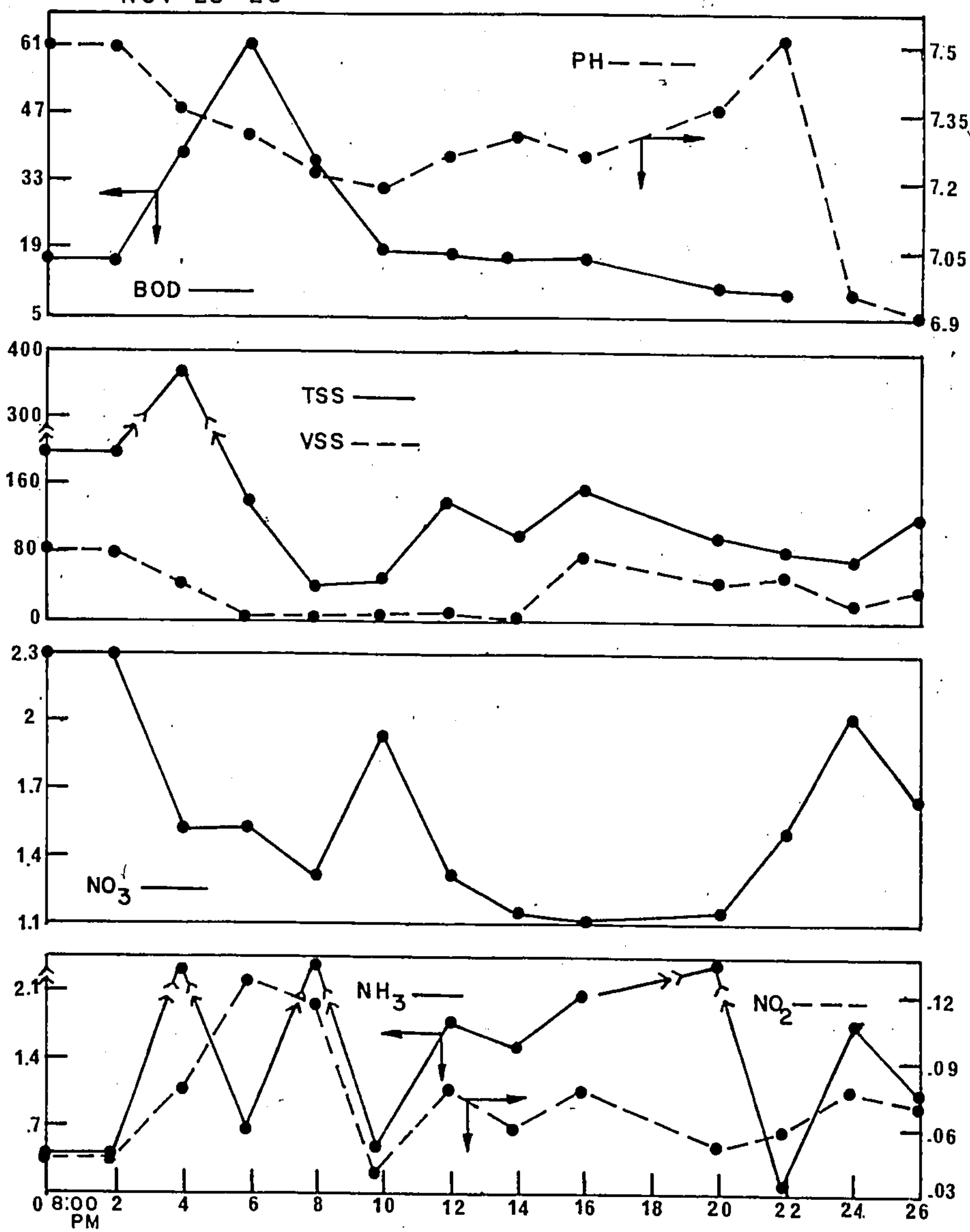

OCT 22—23
T. COL x 10^{-3}
F. COL x 10^{-2}
Cl
SO$_4$
SP. CON.
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE

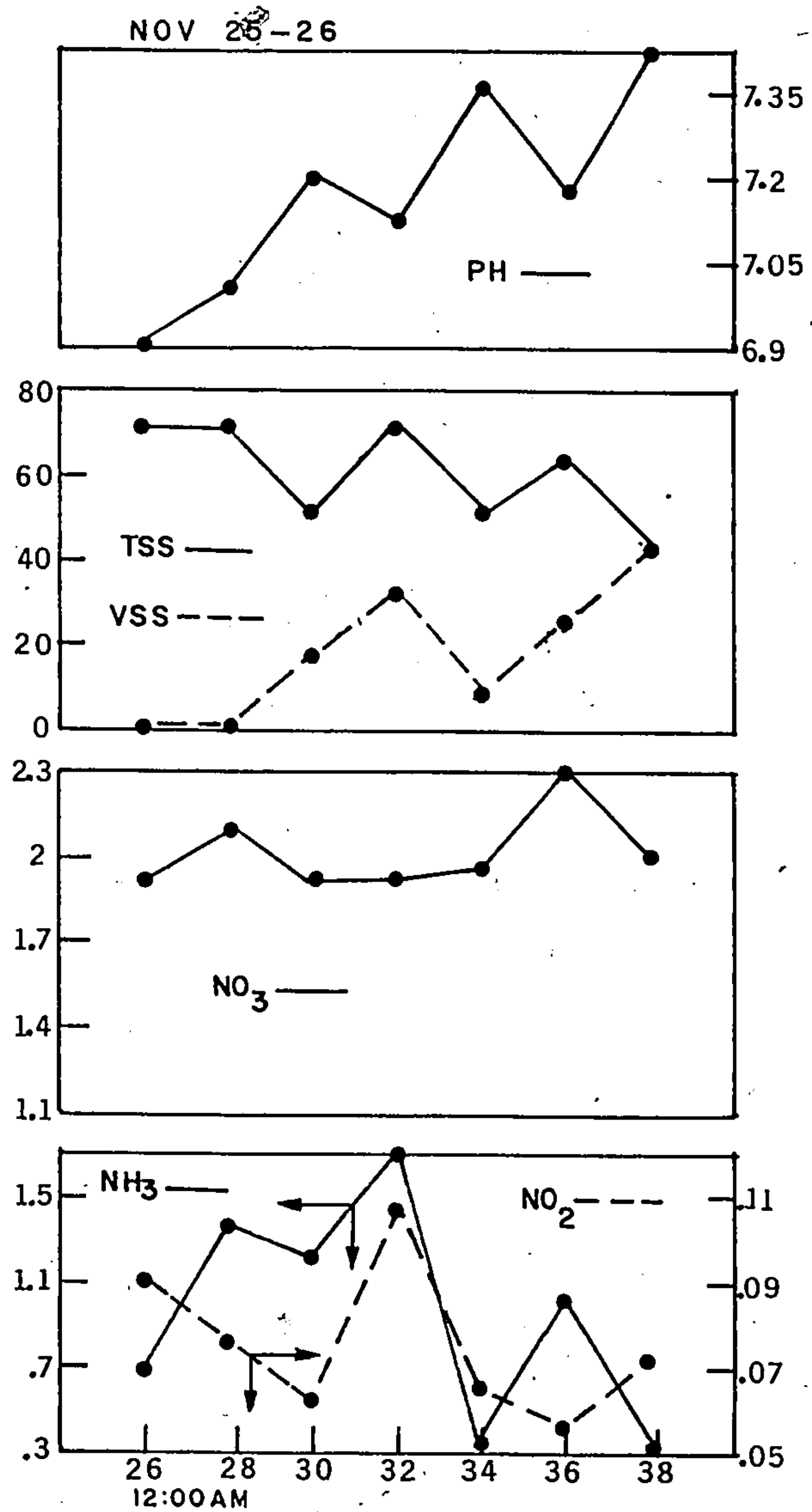

OCT 22-23
T. COL x 10^-4
F. COL x 10^-2
Cl
SO4
SP. CON.
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
7 5 3 1
3 2 1
.27 .21 .15 .09
24 16 8 0
130 100 70 40
.6 .4 .2 0
19 20 21 22 23 24 25 26 27

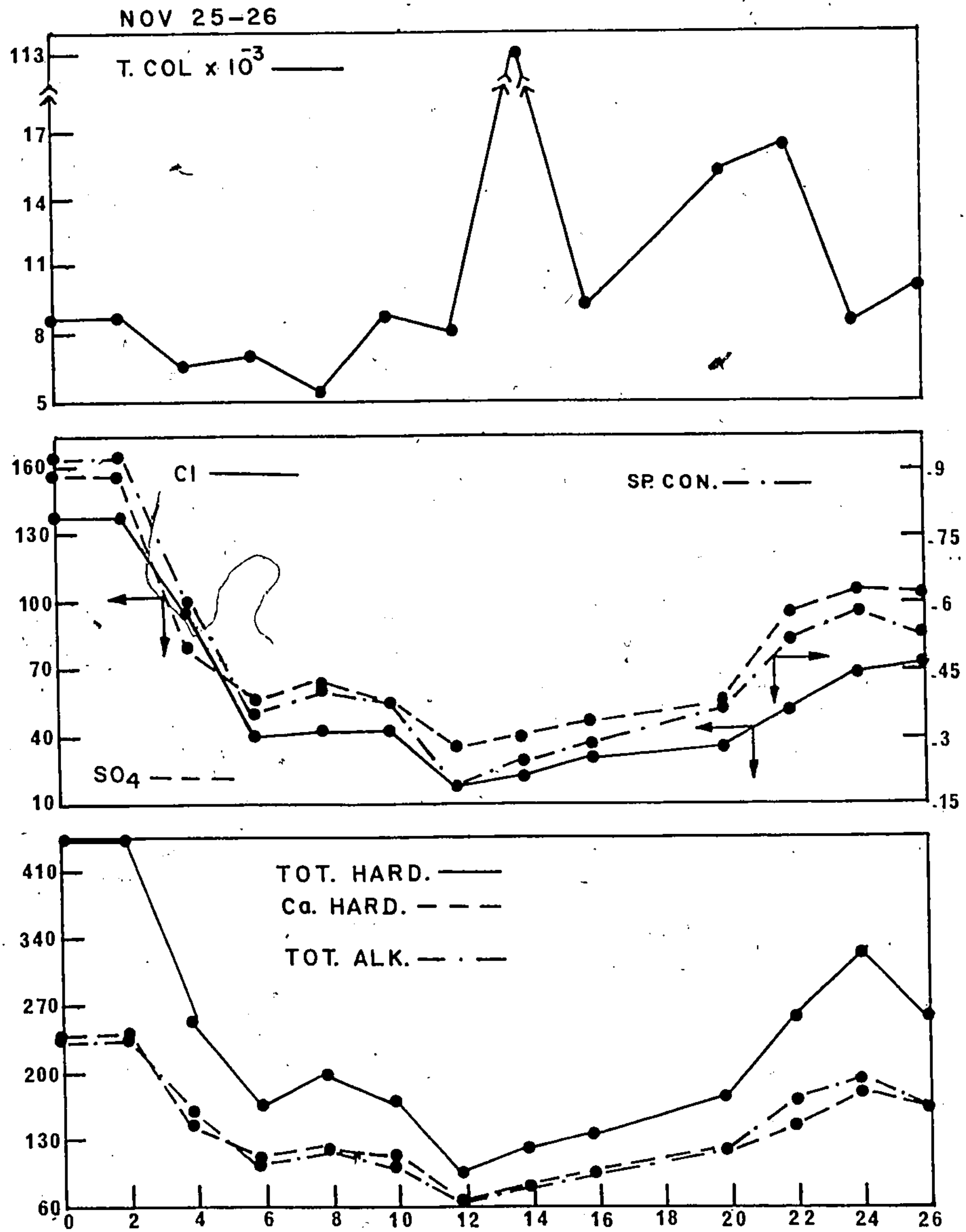

NOV 10-11
PH
BOD
11
8
5
2
7,8
7,6
7,4
7,2
TSS
VSS
190
130
70
10
PO4
NO3
,3
,2
,1
0
1,9
1,6
1,3
1
NH3
NO2
.038
.026
.014
.002
RAINFALL
DISCHARGE
8
6
4
2
0
.3
.2
.1
.05
0 11:45PM 1
2
3
4
5
6

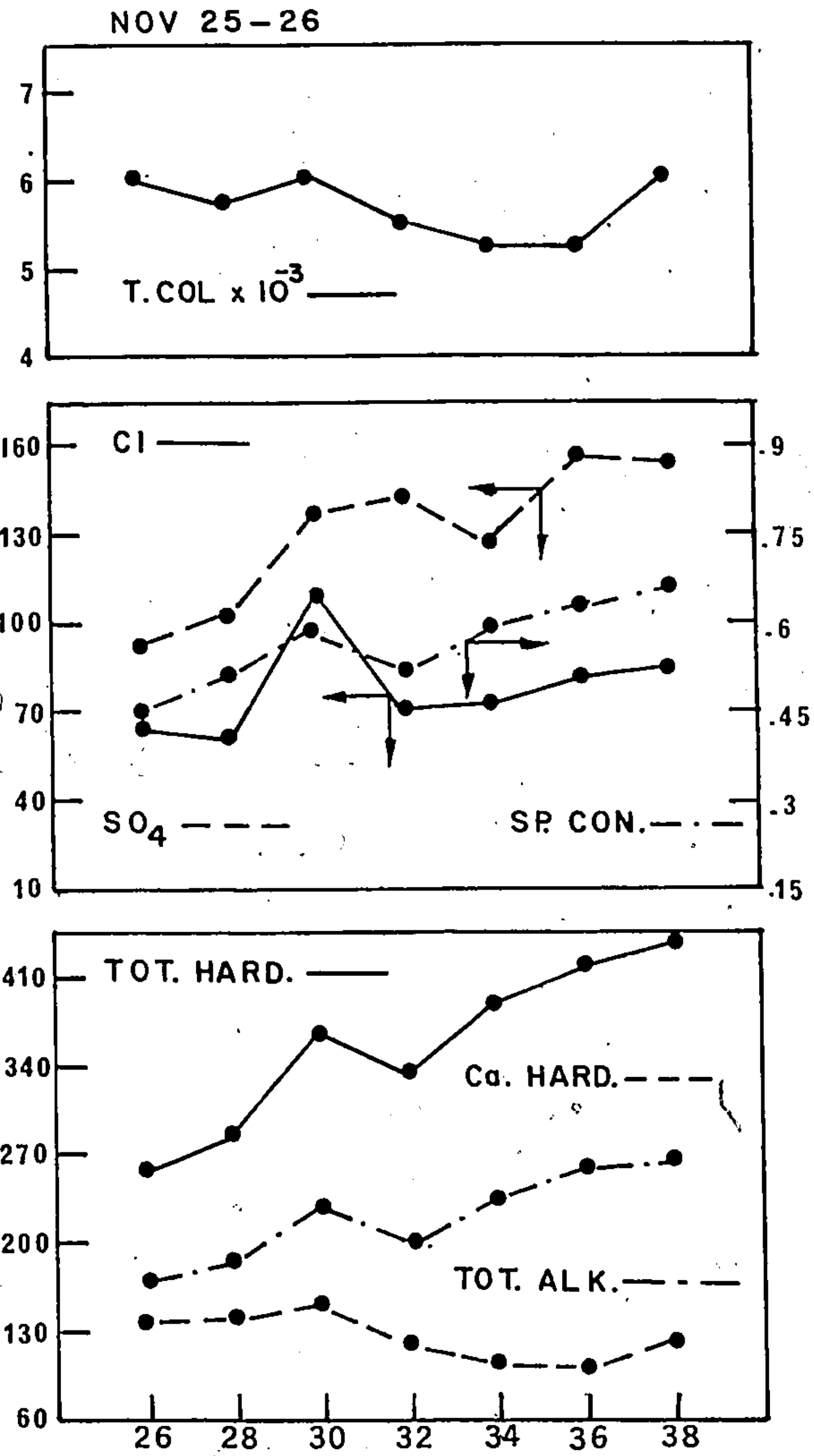

NOV 10 – 11
T. COL x 10^{-3}
F. COL x 10^{-2}
16
14
12
10
8
6
CL
SO4
SP. CON.
100
80
35
25
15
5
.8
.7
.44
.36
.28
.2
TOT. HARD.
Ca. HARD.
TOT. ALK.
350
250
190
150
110
70
DISCHARGE
.2
.15
.1
.05
0
0
1
2
3
4
5
6

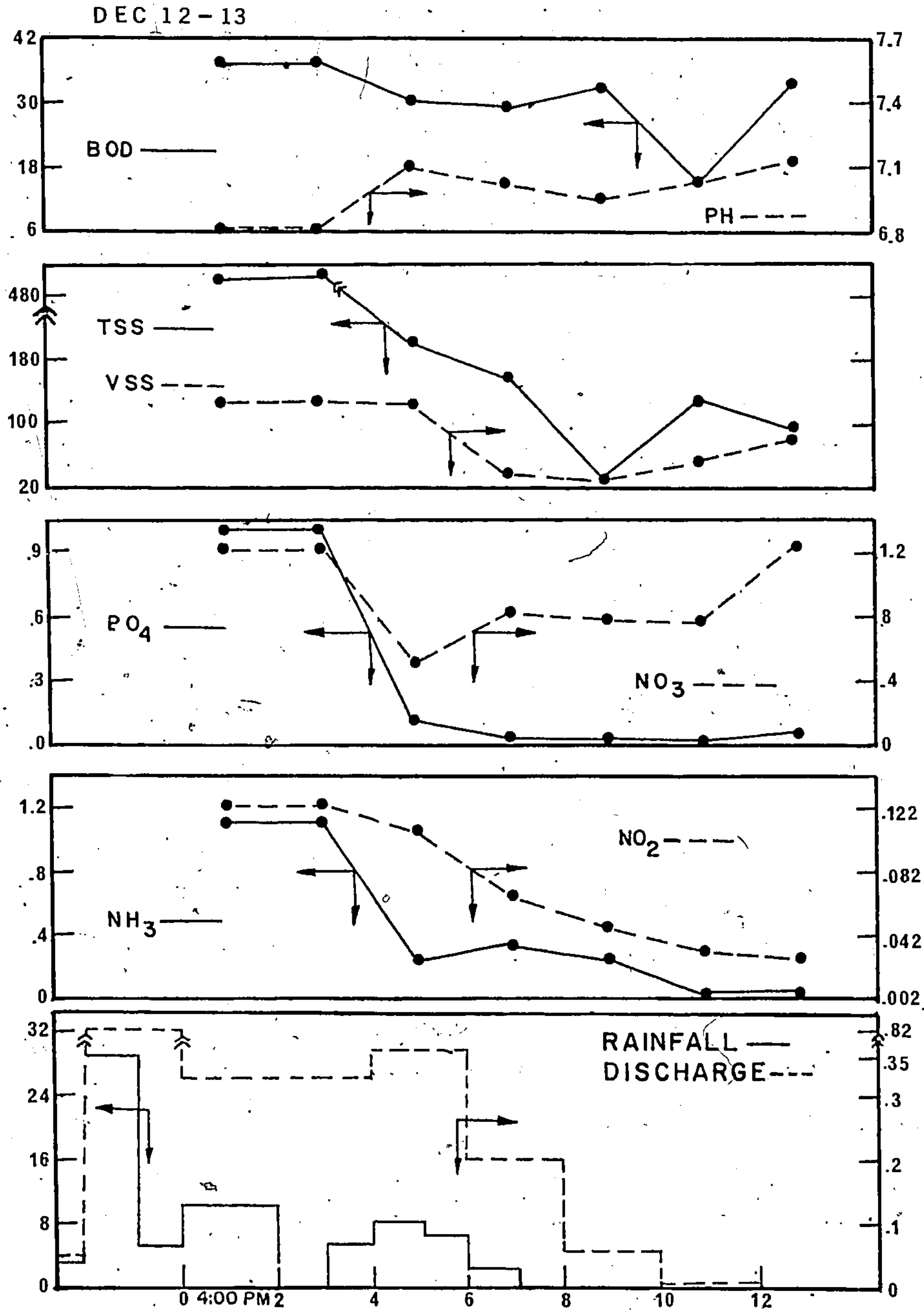
NOV 25-26

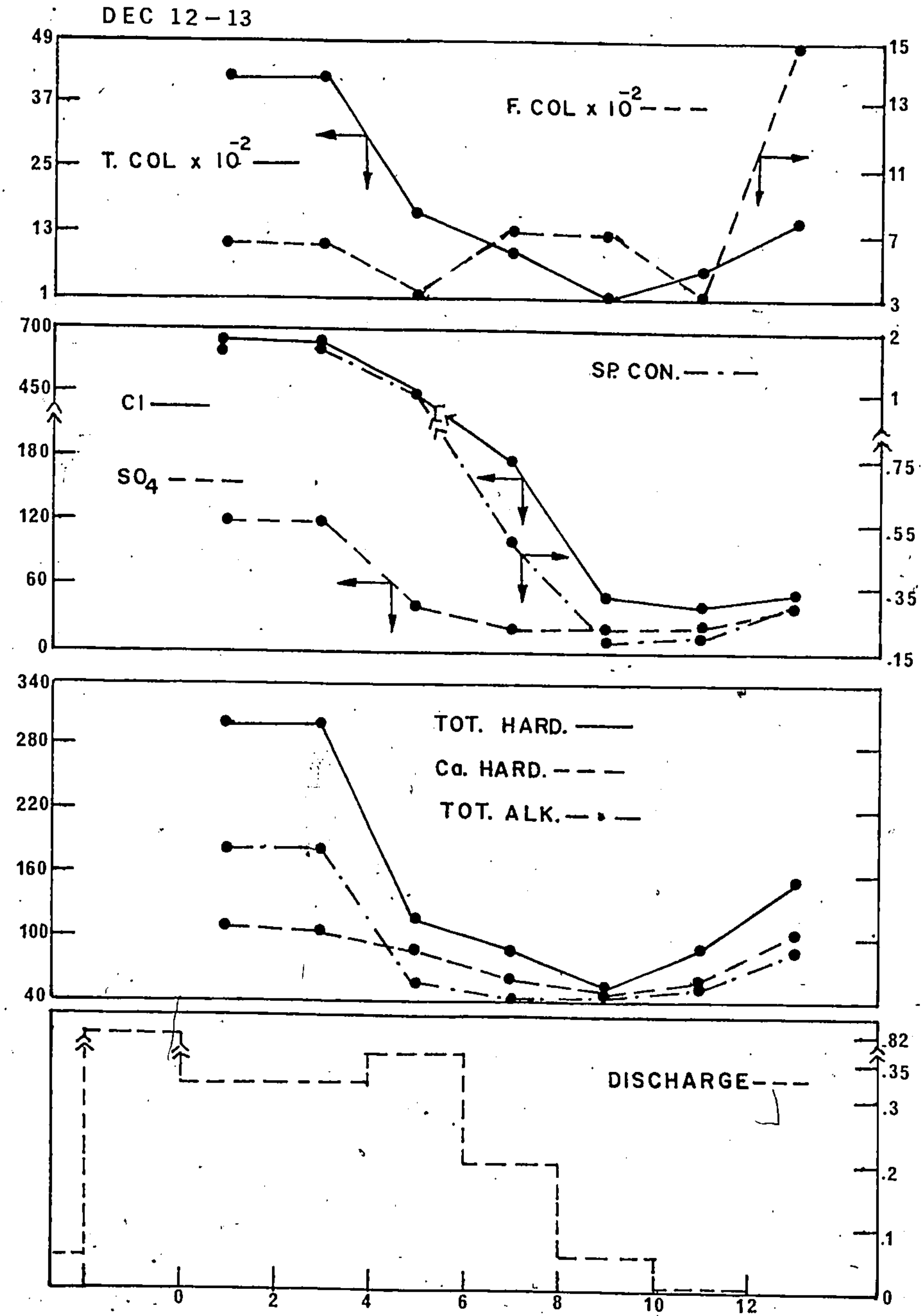

61
47
33
19
5
PH
BOD
7.5
7.35
7.2
7.05
6.9
400
300
160
80
0
TSS
VSS
2.3
2
1.7
1.4
1.1
NO3
2.1
1.4
.7
0
NH3
NO2
.12
.09
.06
.03
8:00 PM
2
4
6
8
10
12
14
16
18
20
22
24
26

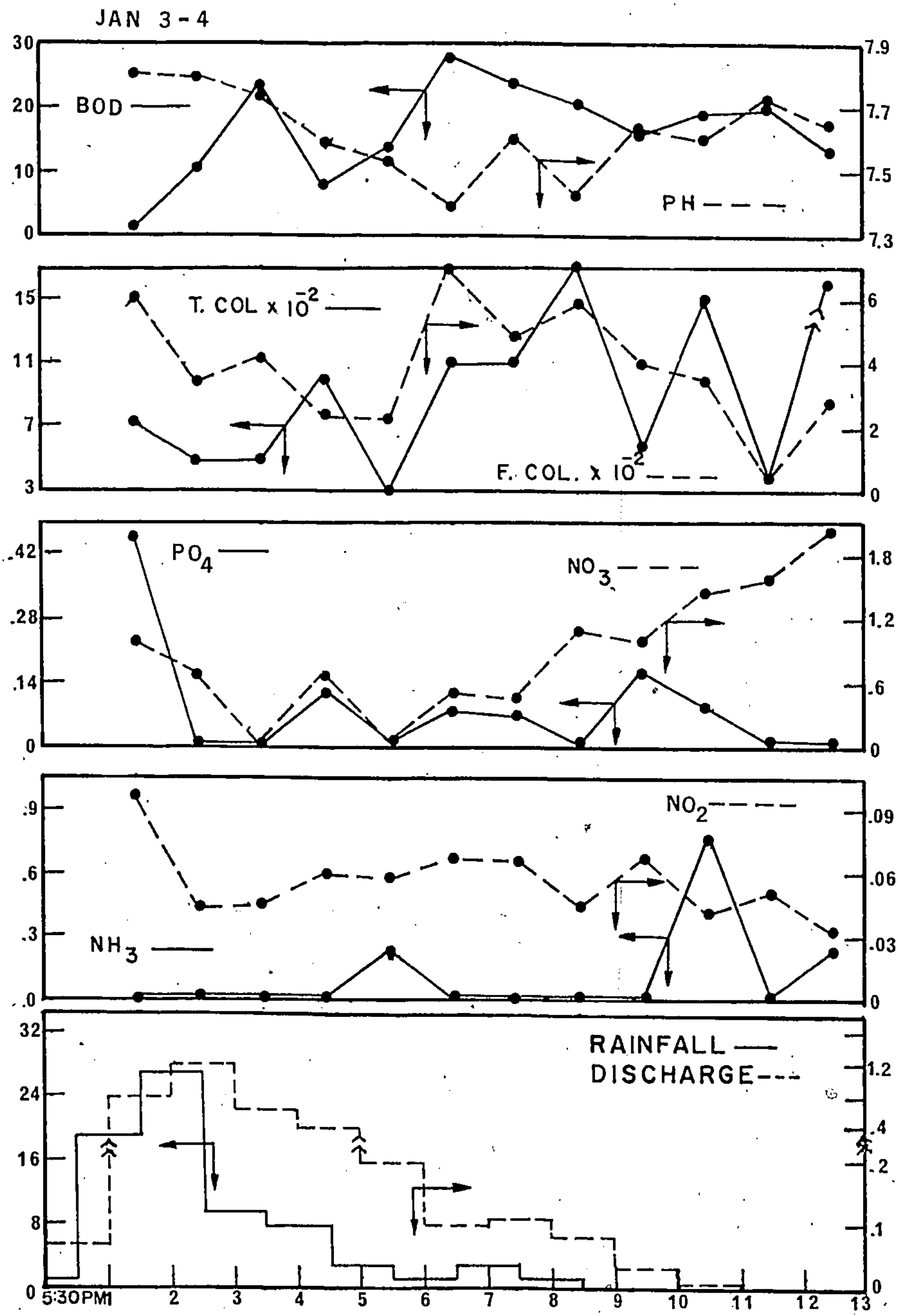

NOV 25-26
PH
7.35
7.2
7.05
6.9
80
60
40
20
0
TSS
VSS
2.3
2
1.7
1.4
1.1
NO3
NH3
NO2
1.5
1.1
.7
.3
.11
.09
.07
.05
26
28
30
32
34
36
38
12:00AM

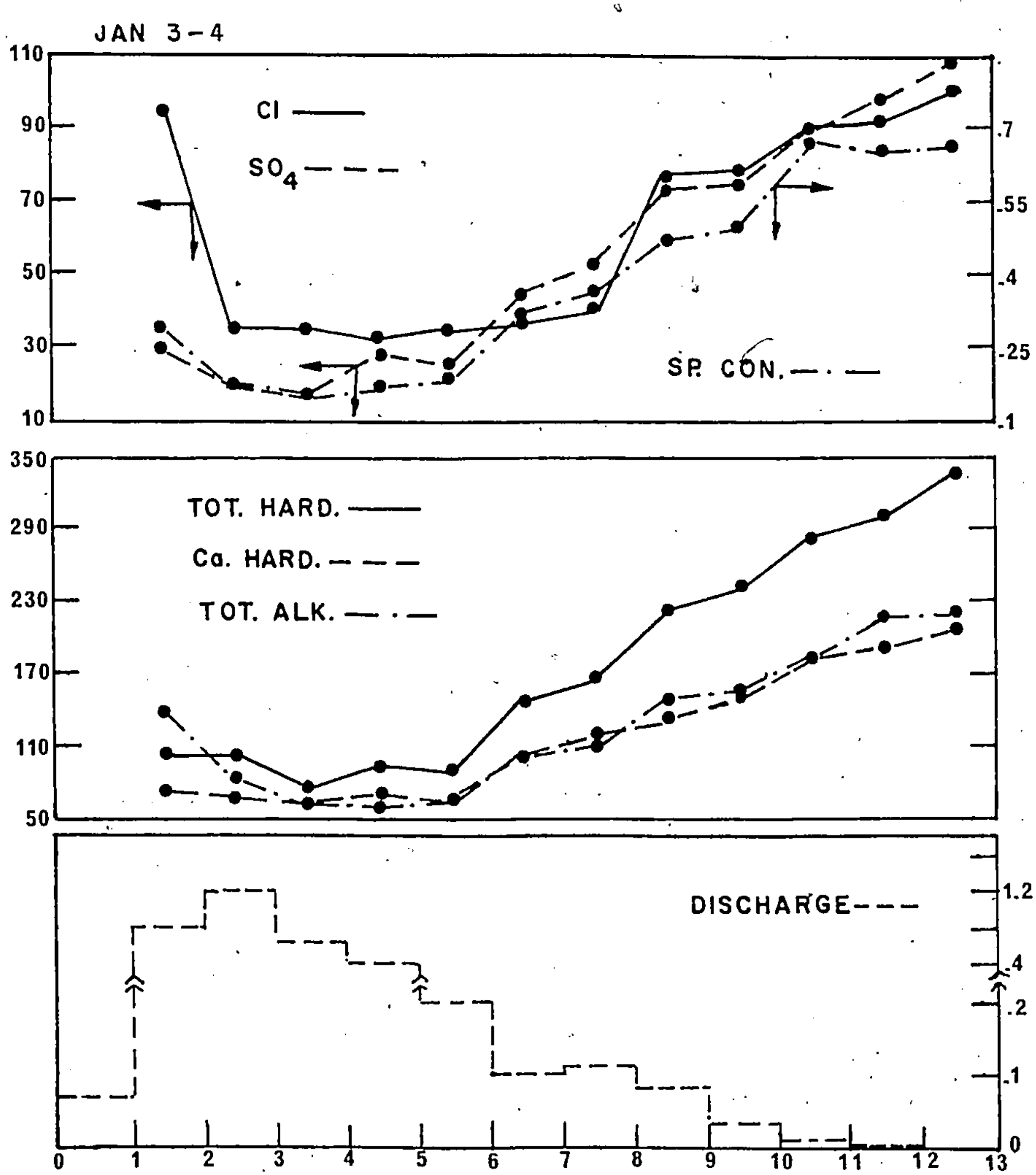

NOV 25-26
T. COL x 10^{-3}
113
17
14
11
8
5
Cl
SP. CON.
SO_4
160
130
100
70
40
10
.9
.75
.6
.45
.3
.15
TOT. HARD.
Ca. HARD.
TOT. ALK.
410
340
270
200
130
60
0 2 4 6 8 10 12 14 16 18 20 22 24 26


NOV 25-26
7
6
5
4
T.COL x 10^-3
160
130
100
70
40
10
Cl
SO4
SP. CON.
.9
.75
.6
.45
.3
.15
410
340
270
200
130
60
TOT. HARD.
Ca. HARD.
TOT. ALK.
26
28
30
32
34
36
38

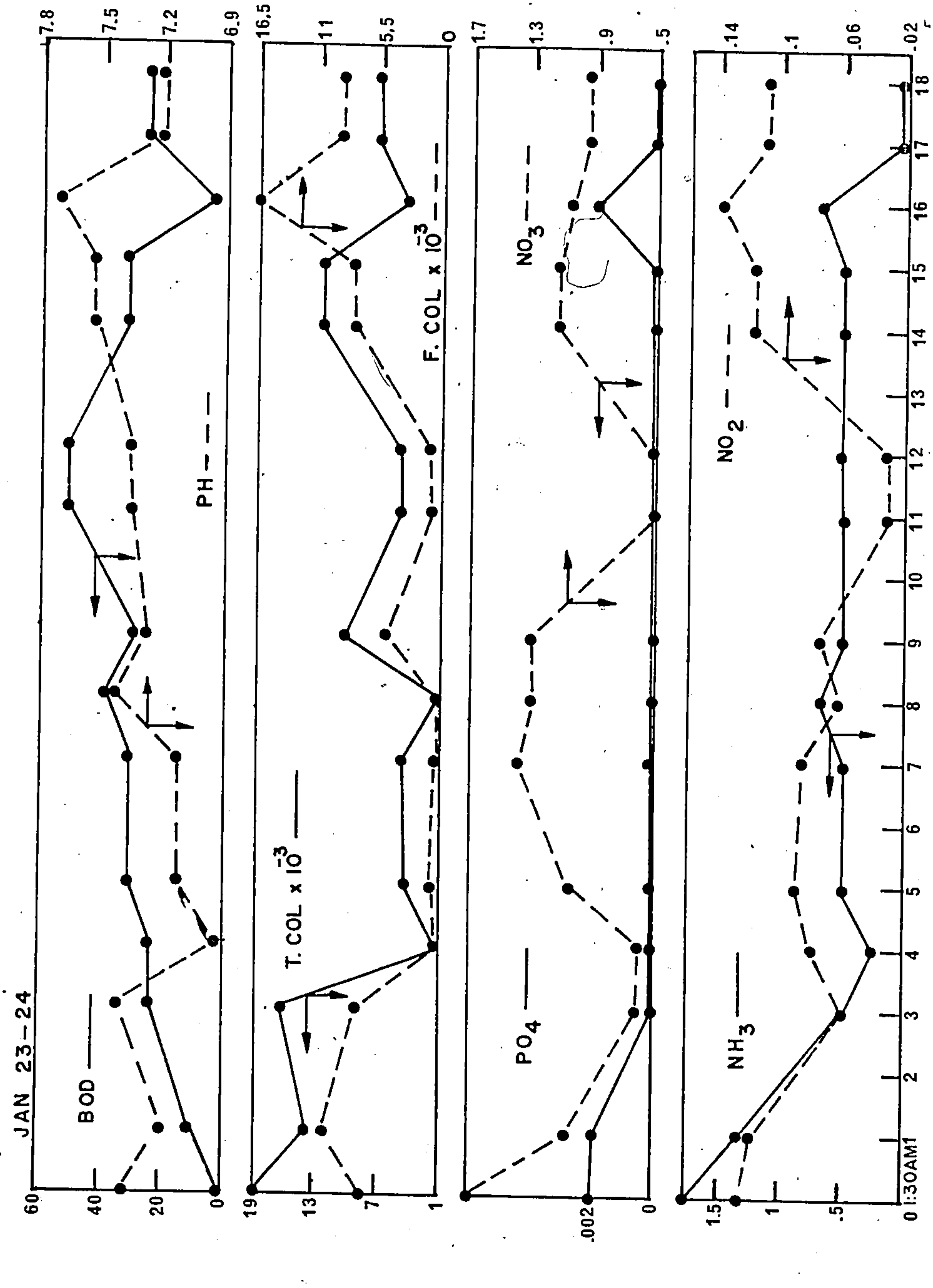

DEC 12-13
42
30
18
6
7.7
7.4
7.1
6.8
BOD
PH
480
180
100
20
TSS
VSS
.9
.6
.3
.0
1.2
.8
.4
0
PO4
NO3
1.2
.8
.4
0
.122
.082
.042
.002
NH3
NO2
32
24
16
8
0
.82
.35
.3
.2
.1
0
RAINFALL
DISCHARGE
0 4:00 PM 2
4
6
8
10
12

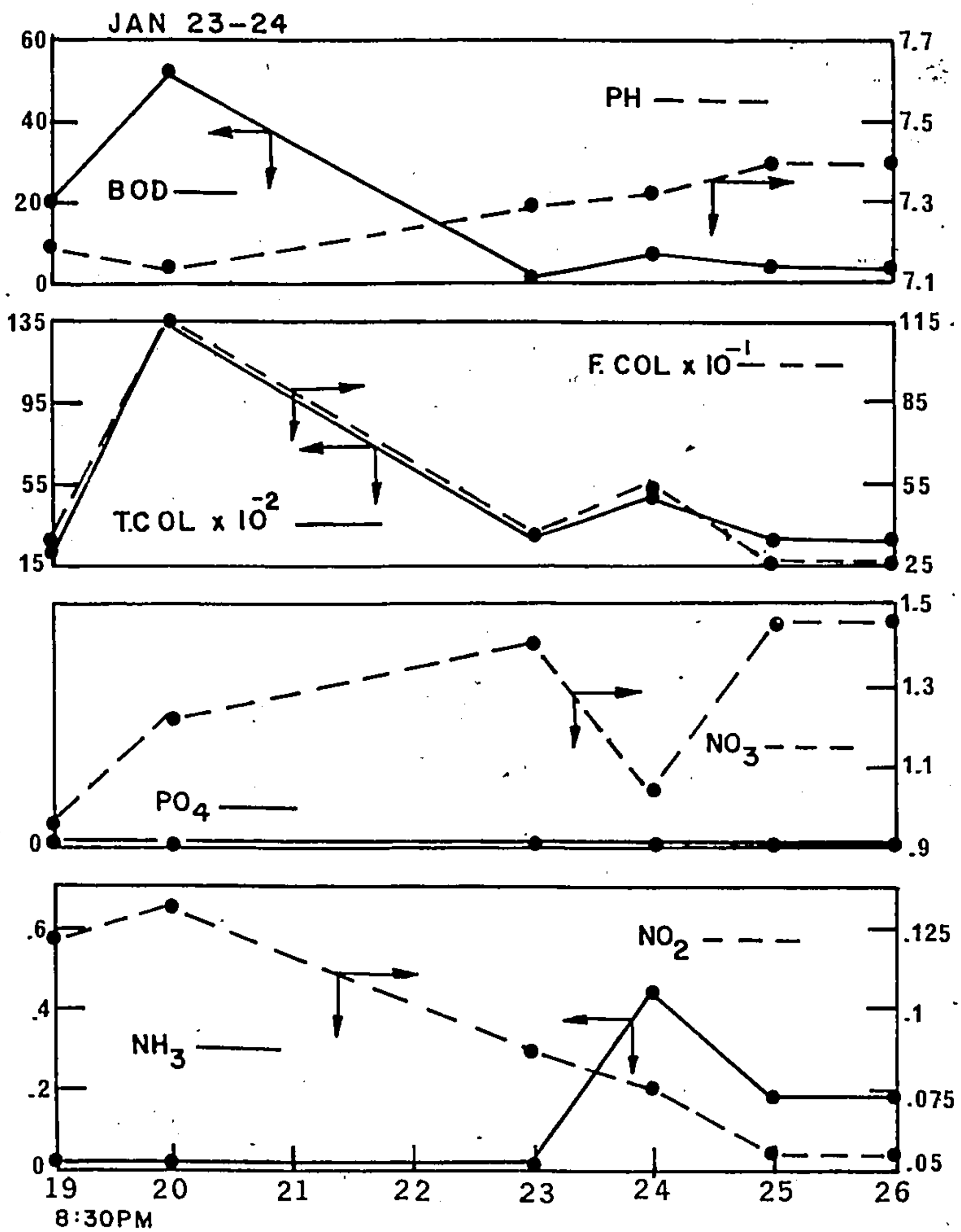

DEC 12 – 13
49
37
25
13
1
15
13
11
7
3
F. COL x 10^{-2}
T. COL x 10^{-2}
700
450
180
120
60
0
2
1
.75
.55
.35
.15
SP. CON.
Cl
SO_4
340
280
220
160
100
40
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
.82
.35
.3
.2
.1
0
0
2
4
6
8
10
12


JAN 3-4
BOD
PH
T. COL x 10^{-2}
F. COL. x 10^{-2}
PO_4
NO_3
NO_2
NH_3
RAINFALL
DISCHARGE
5:30PM

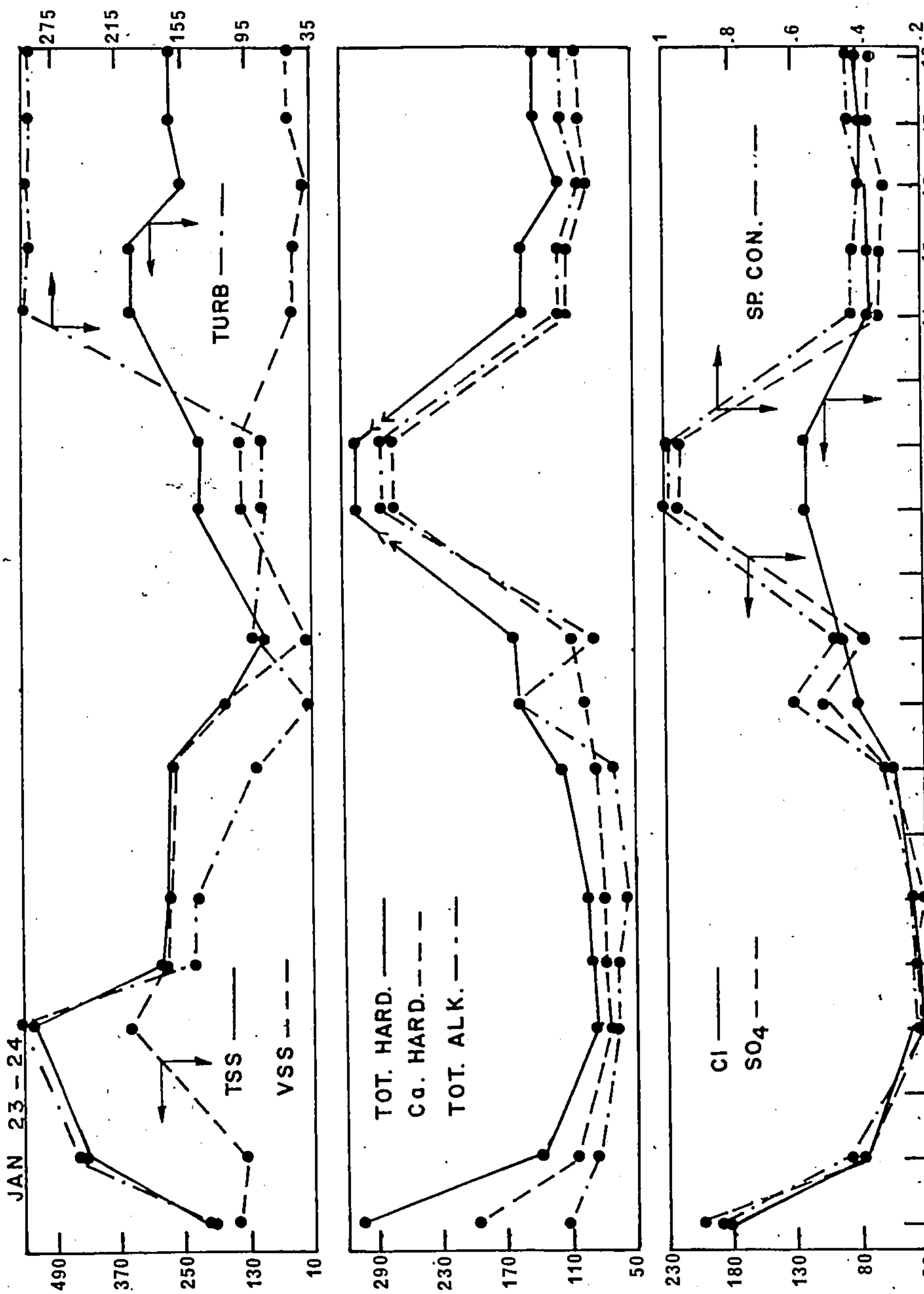


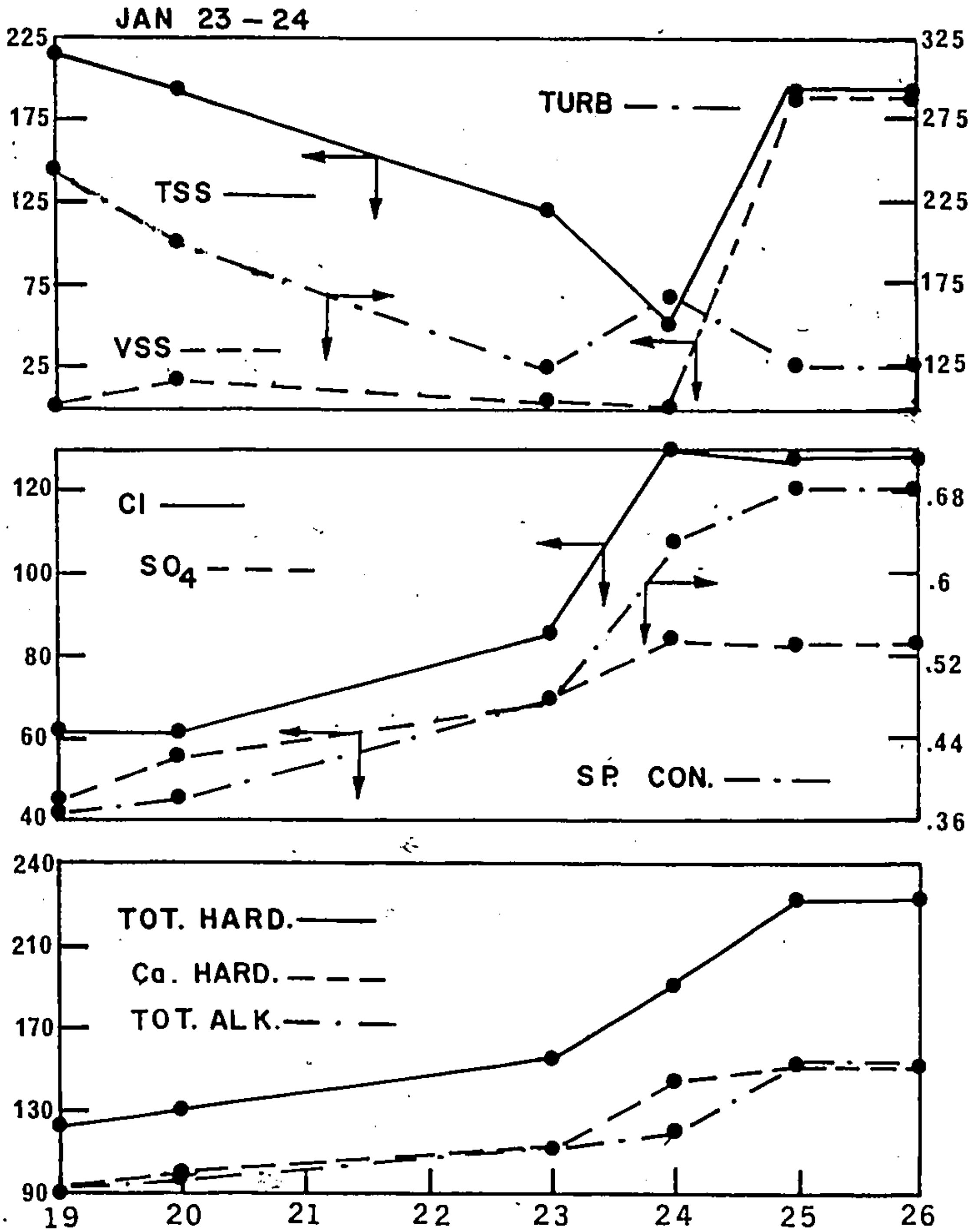
JAN 3-4
Cl
SO4
SP. CON.
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
110
90
70
50
30
10
.7
.55
.4
.25
.1
350
290
230
170
110
50
1.2
.4
.2
.1
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13


JAN 23-24
BOD ——
PH - - -
T. COL x 10^-3 ——
F. COL x 10^-3 - - -
PO4 ——
NO3 - - -
NH3 ——
NO2 - - -
0 1:30AM 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
60 40 20 0
7.8 7.5 7.2 6.9
19 13 7 1
16.5 11 5.5 0
.002 0
1.7 1.3 .9 .5
1.5 1 .5 0
.14 .1 .06 .02



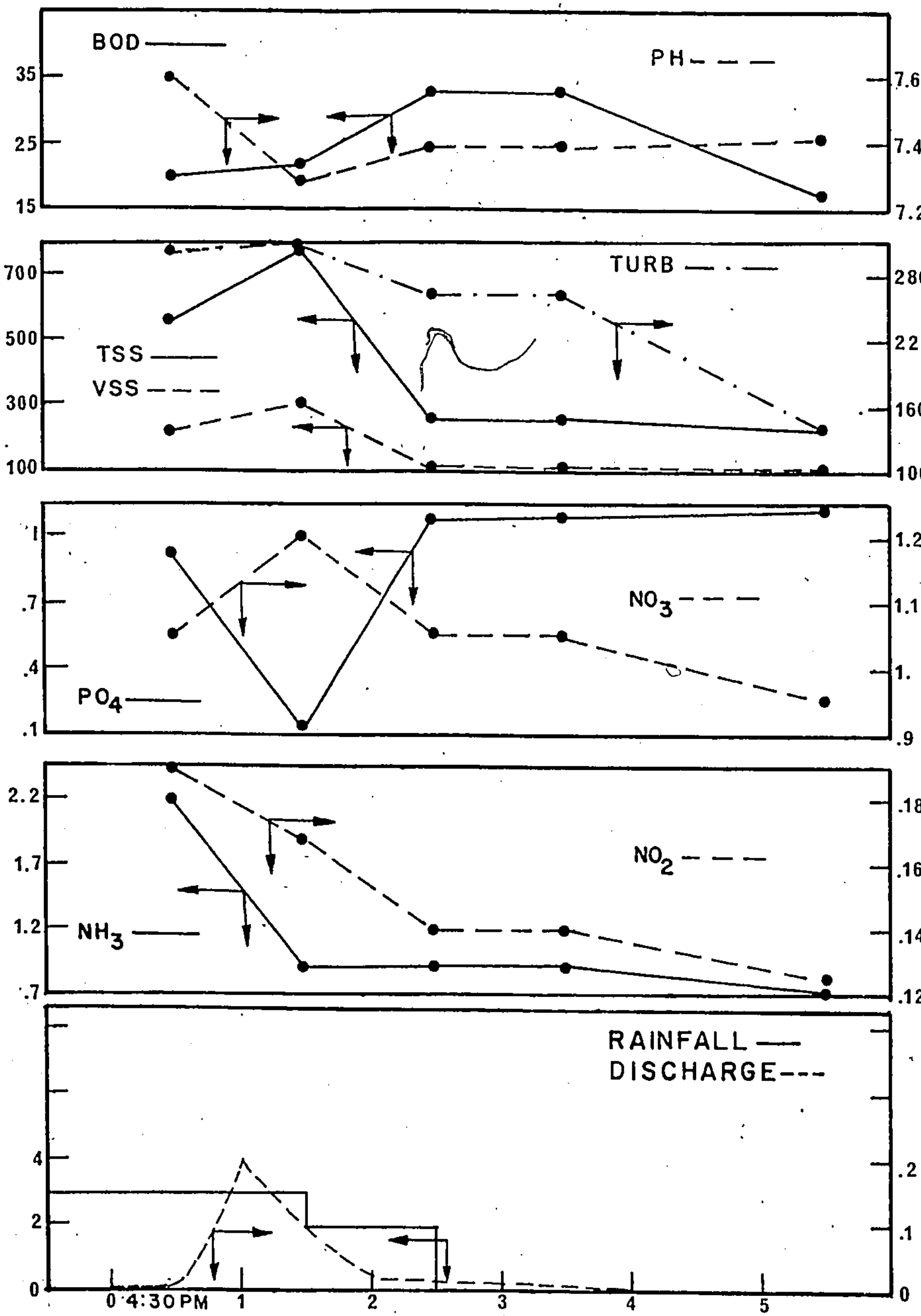
JAN 23-24
60
40
20
0
7.7
7.5
7.3
7.1
PH
BOD
135
95
55
15
115
85
55
25
F. COL x 10⁻¹
T.COL x 10⁻²
1.5
1.3
1.1
.9
0
NO3
PO4
.6
.4
.2
0
.125
.1
.075
.05
NO2
NH3
19
20
21
22
23
24
25
26
8:30PM


JAN 23 - 24
TSS ——
VSS — — —
TURB — · —
TOT. HARD. ——
Ca. HARD. — — —
TOT. ALK. — · —
Cl ——
SO_4 — — —
SP. CON. — · —
490 370 250 130 10
275 215 155 95 35
290 230 170 110 50
230 180 130 80 30
1 .8 .6 .4 .2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

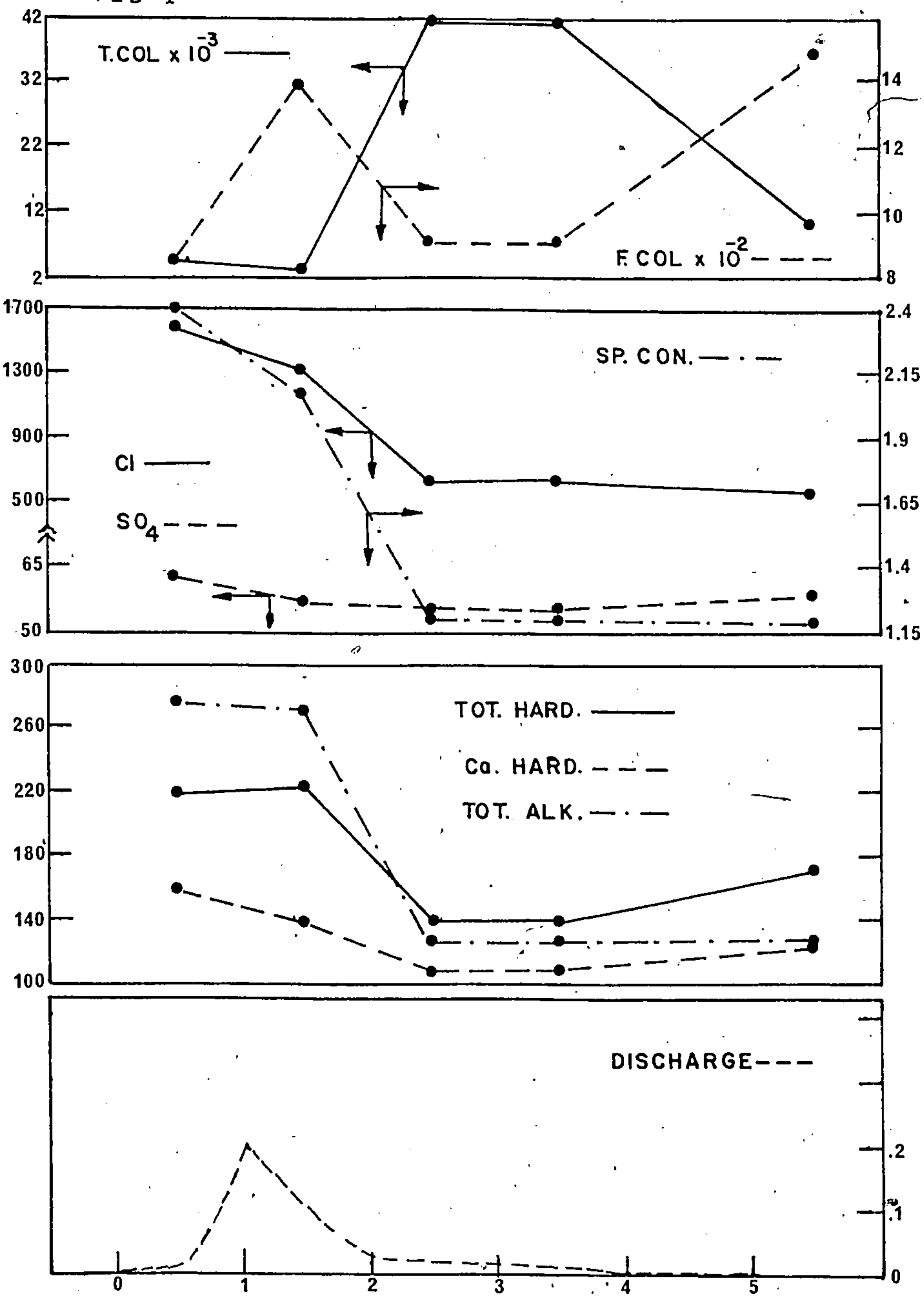


JAN 23 – 24
225
175
125
75
25
325
275
225
175
125
TURB
TSS
VSS
120
100
80
60
40
.68
.6
.52
.44
.36
Cl
SO_4
SP. CON.
240
210
170
130
90
TOT. HARD.
Ca. HARD.
TOT. ALK.
19
20
21
22
23
24
25
26

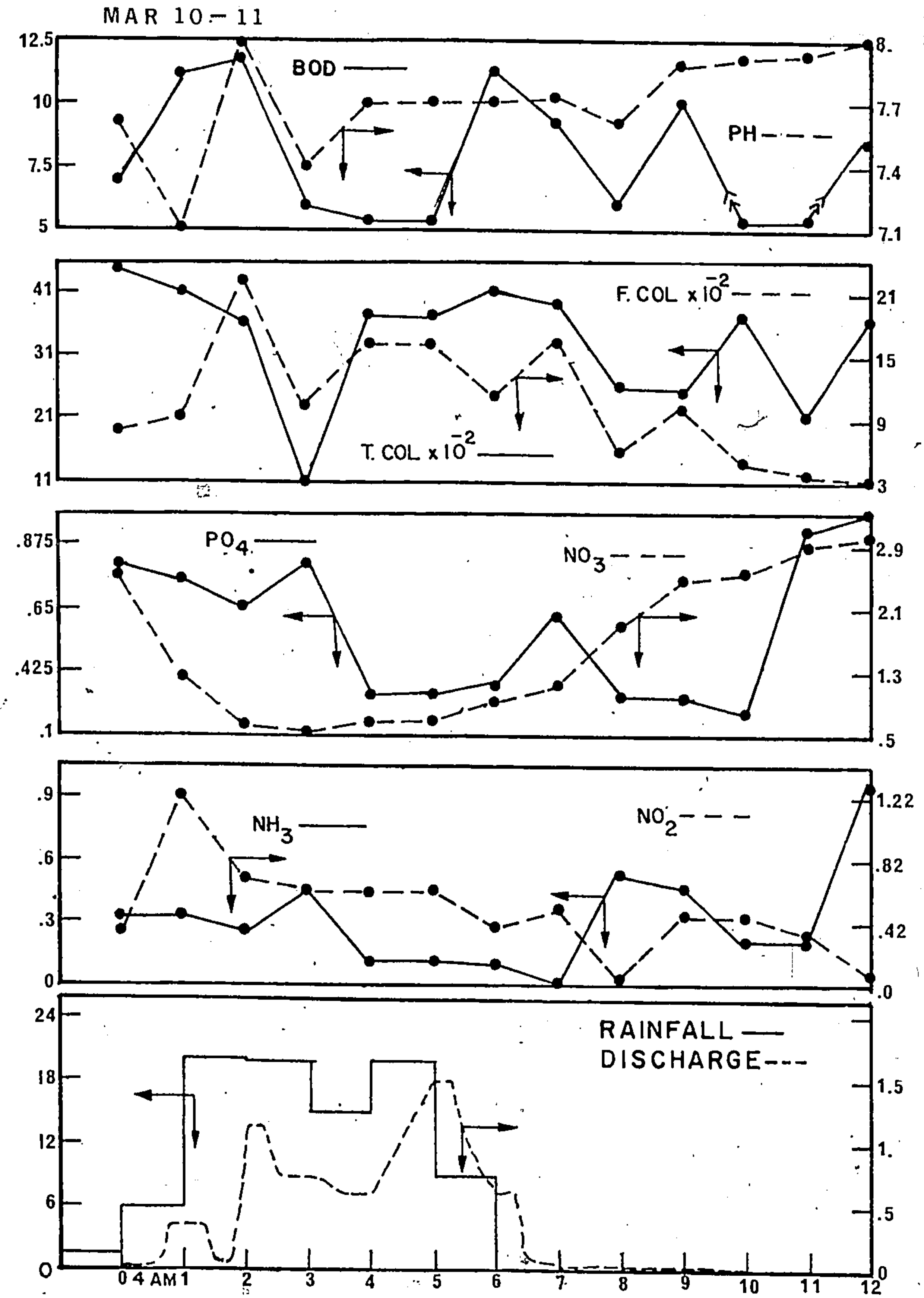
FEB 1


BOD
PH
35
25
15
7.6
7.4
7.2
TURB
700
500
300
100
280
220
160
100
TSS
VSS
1
.7
.4
.1
1.2
1.1
1.
.9
NO_3
PO_4
2.2
1.7
1.2
.7
.18
.16
.14
.12
NO_2
NH_3
RAINFALL
DISCHARGE
4
2
0
.2
.1
0
0 4:30PM
1
2
3
4
5

FEB 1

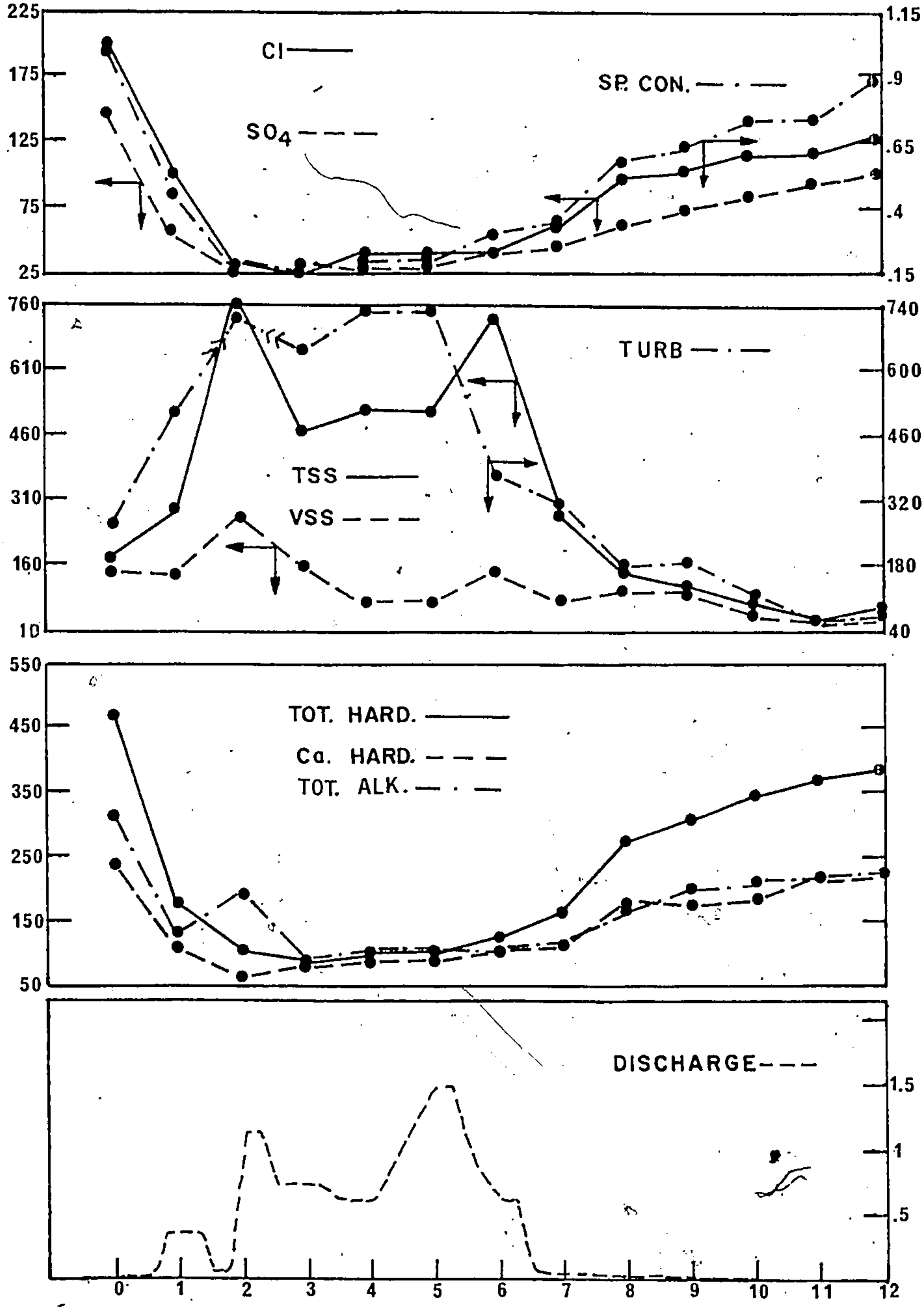


T. COL x 10^{-3}
F. COL x 10^{-2}
SP. CON.
Cl
SO_4
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
42
32
22
12
2
14
12
10
8
1700
1300
900
500
65
50
2.4
2.15
1.9
1.65
1.4
1.15
300
260
220
180
140
100
.2
.1
0
1
2
3
4
5

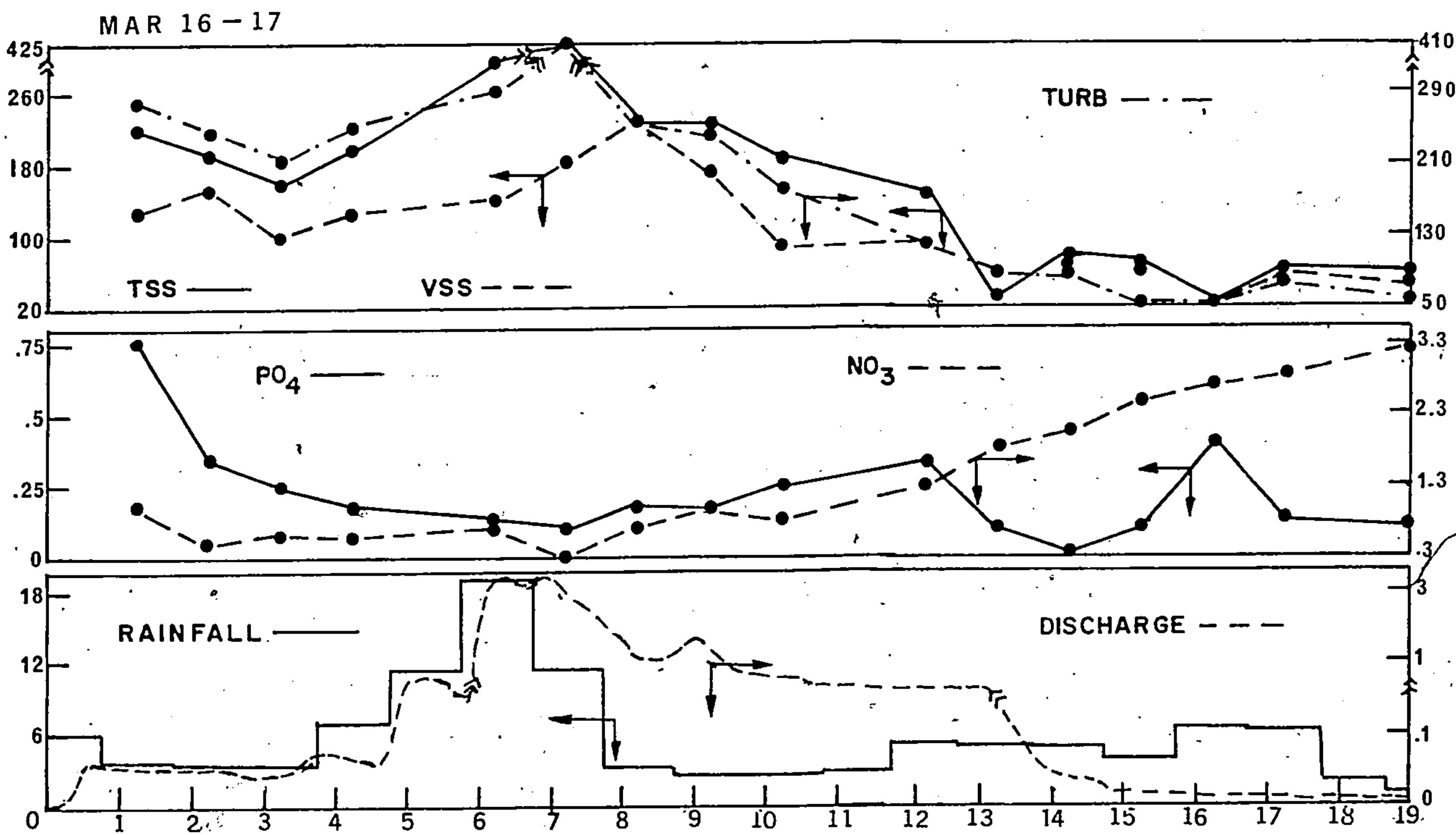


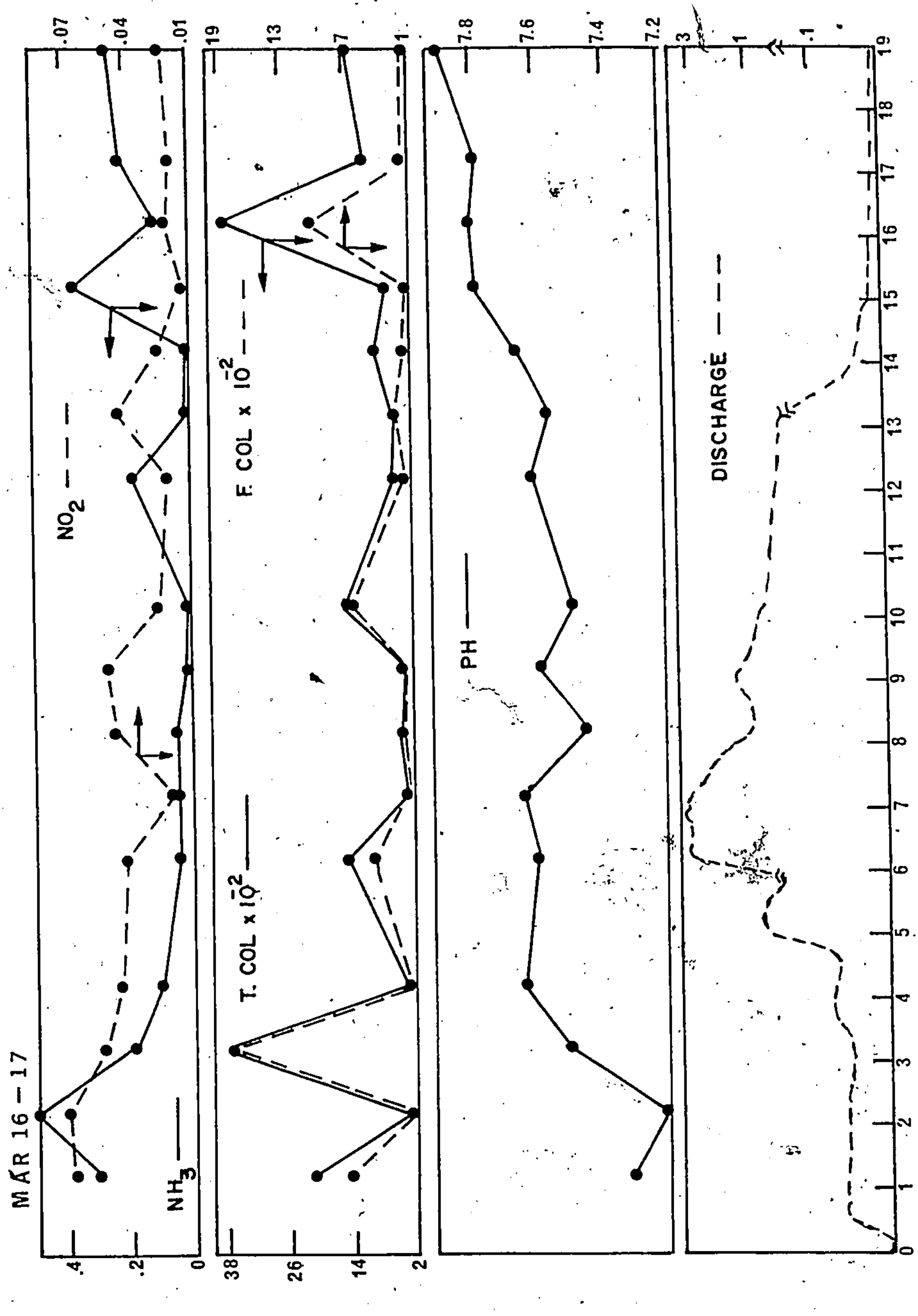
MAR 10 - 11
BOD
PH
F. COL x 10^{-2}
T. COL x 10^{-2}
PO_4
NO_3
NH_3
NO_2
RAINFALL
DISCHARGE
12.5
10
7.5
5
8.
7.7
7.4
7.1
41
31
21
11
21
15
9
3
.875
.65
.425
.1
2.9
2.1
1.3
.5
.9
.6
.3
0
1.22
.82
.42
.0
24
18
12
6
0
1.5
1.
.5
0
0 4 AM 1
2
3
4
5
6
7
8
9
10
11
12

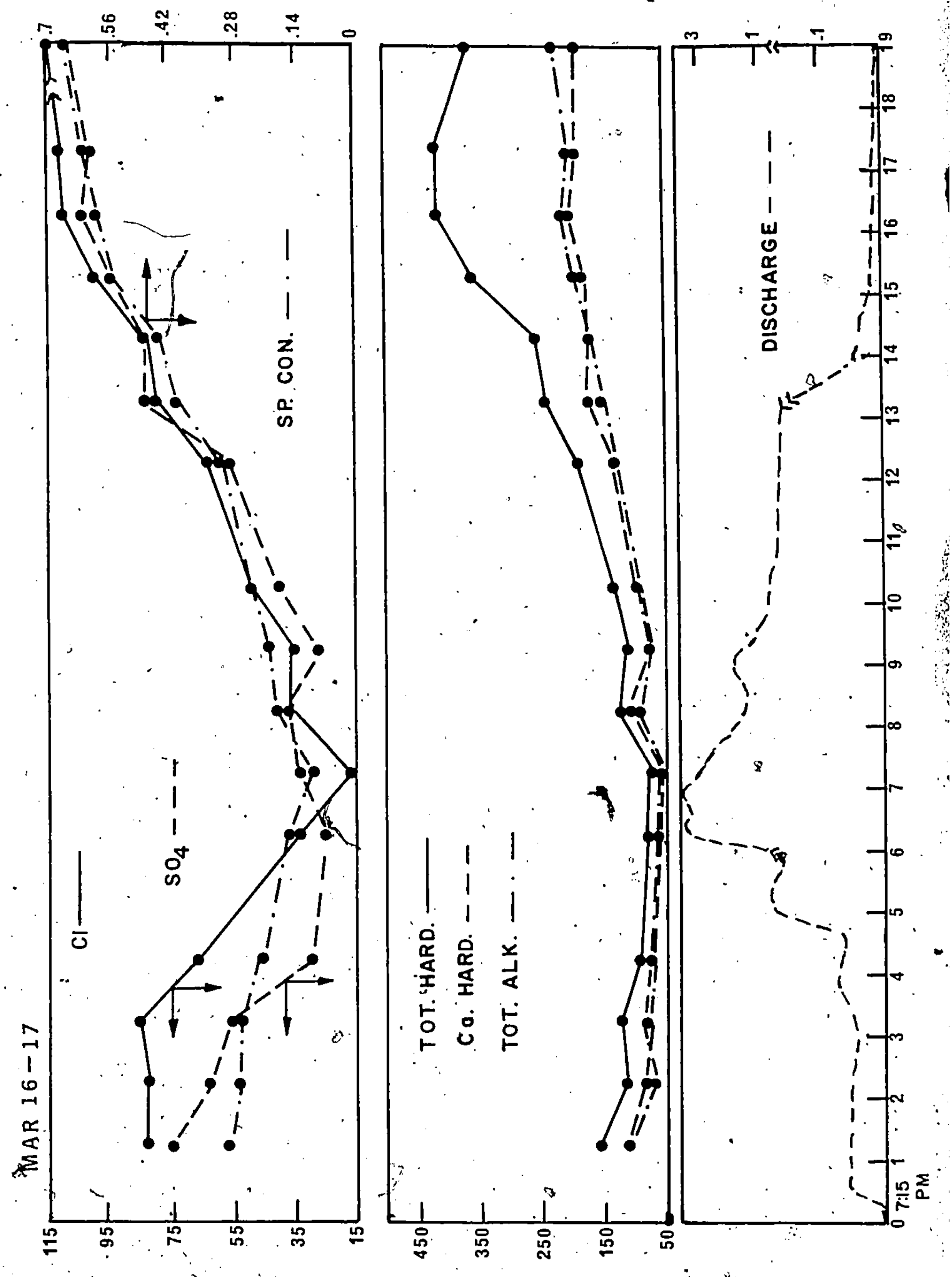
MAR 10–11

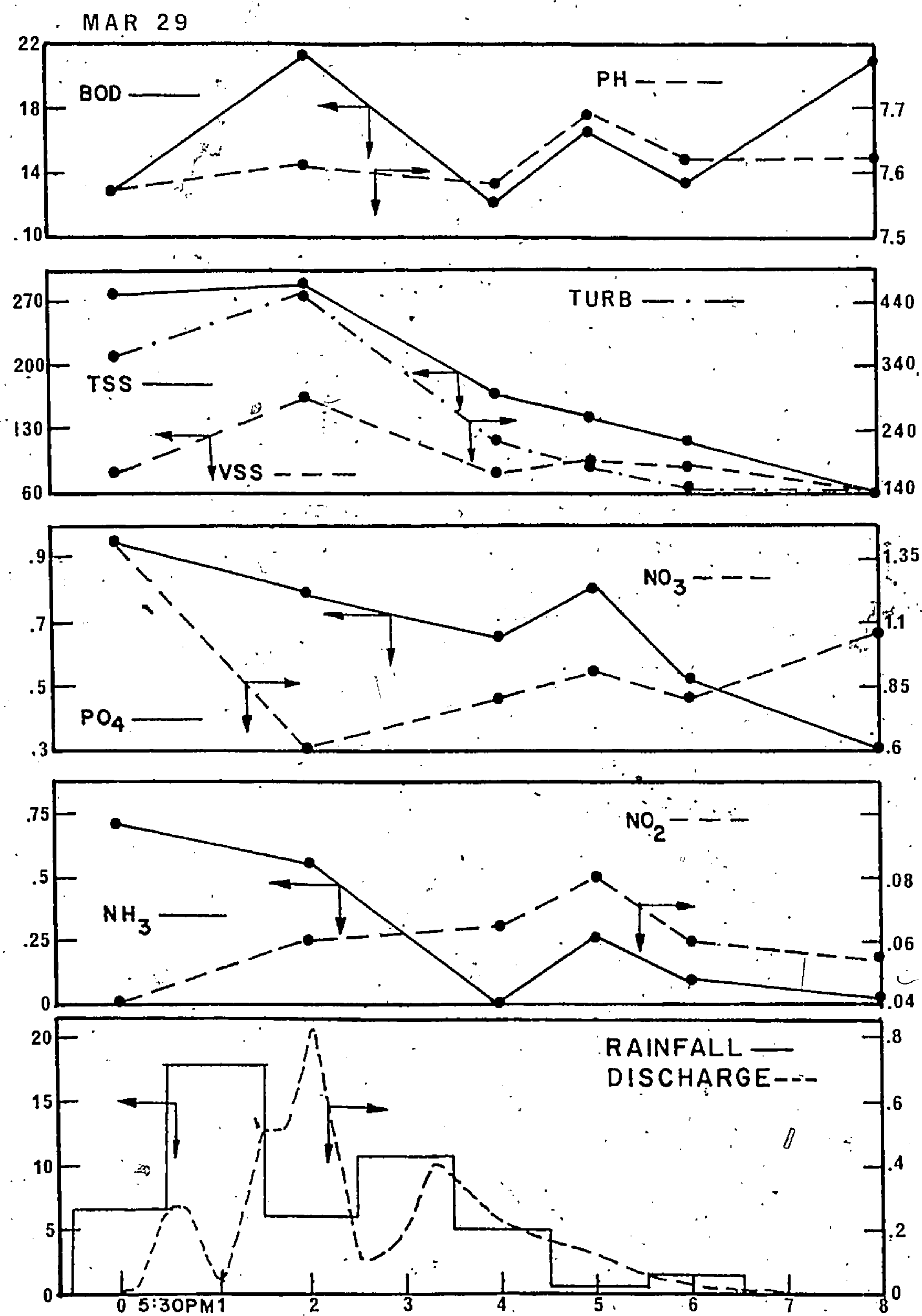


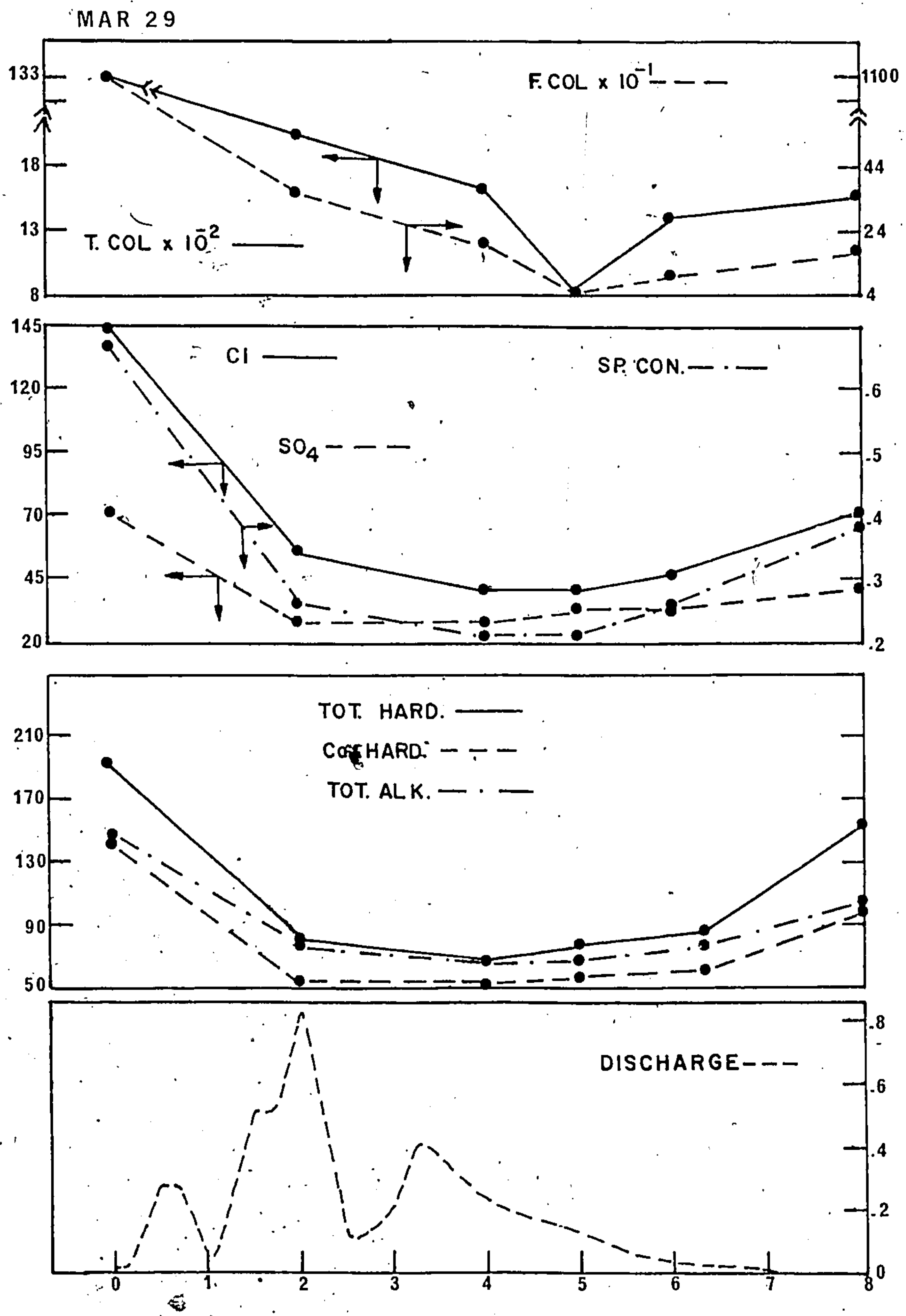
225
175
125
75
25
1.15
.9
.65
.4
.15
Cl
SP. CON.
SO4
760
610
460
310
160
10
740
600
460
320
180
40
TURB
TSS
VSS
550
450
350
250
150
50
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
1.5
1
.5
0
1
2
3
4
5
6
7
8
9
10
11
12

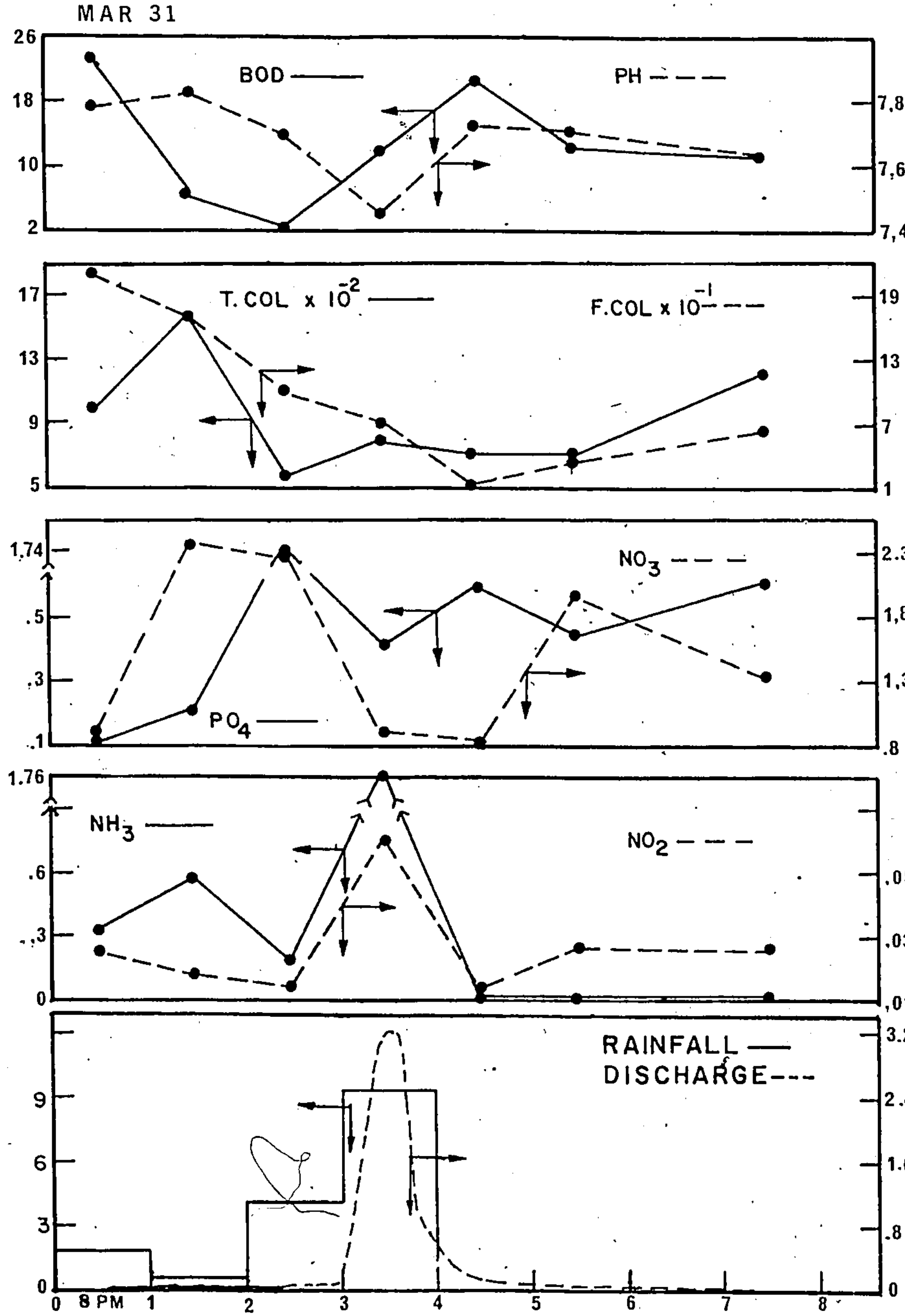

MAR 16 — 17
425
260
180
100
20
TSS
VSS
TURB
410
290
210
130
50
.75
.5
.25
0
PO4
NO3
3.3
2.3
1.3
.3
18
12
6
0
RAINFALL
DISCHARGE
3
1
.1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

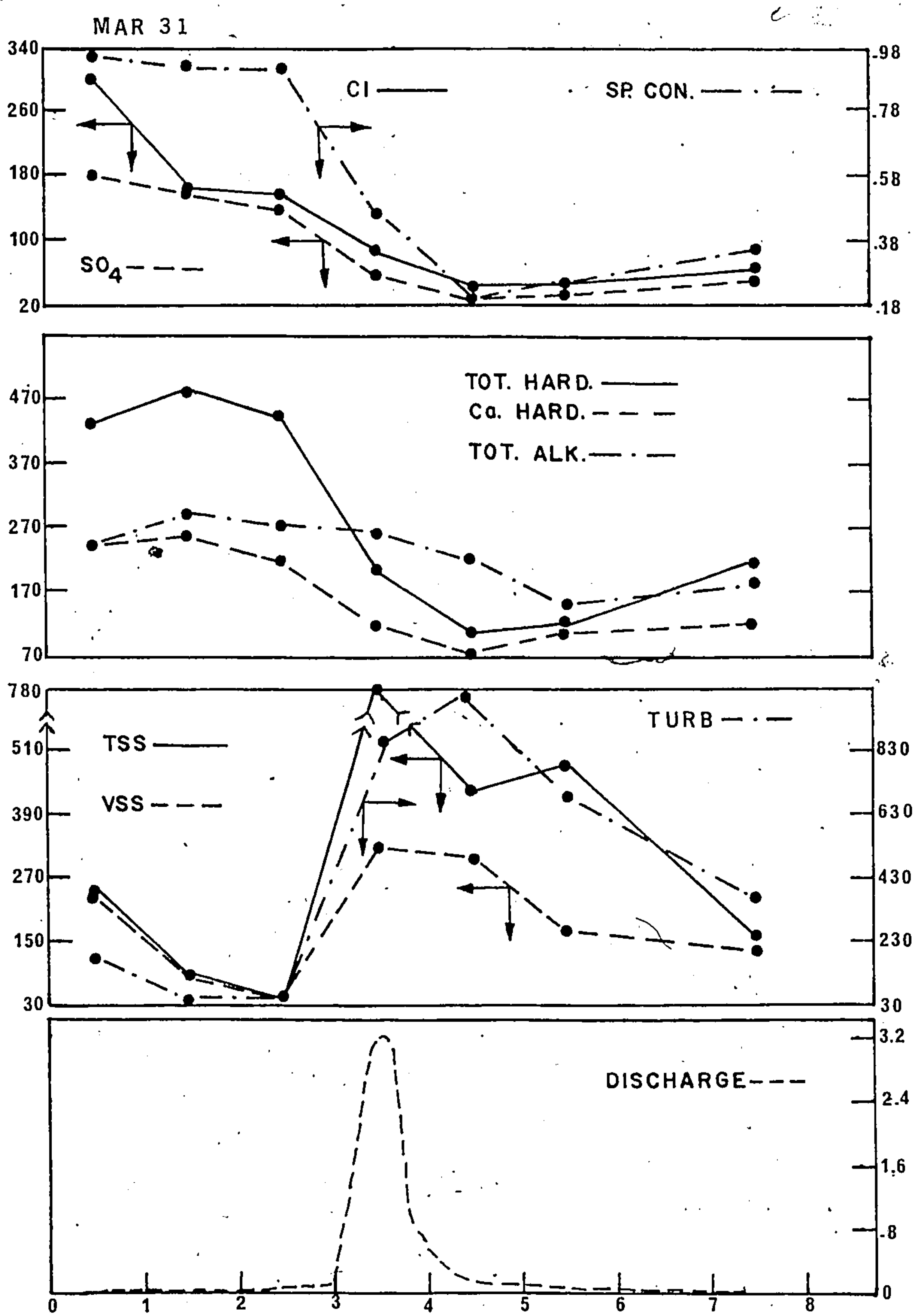

MAR 16 — 17
NH3 ——
NO2 — — —
T. COL x 10-2 ——
F. COL x 10-2 — — —
PH ——
DISCHARGE — — —

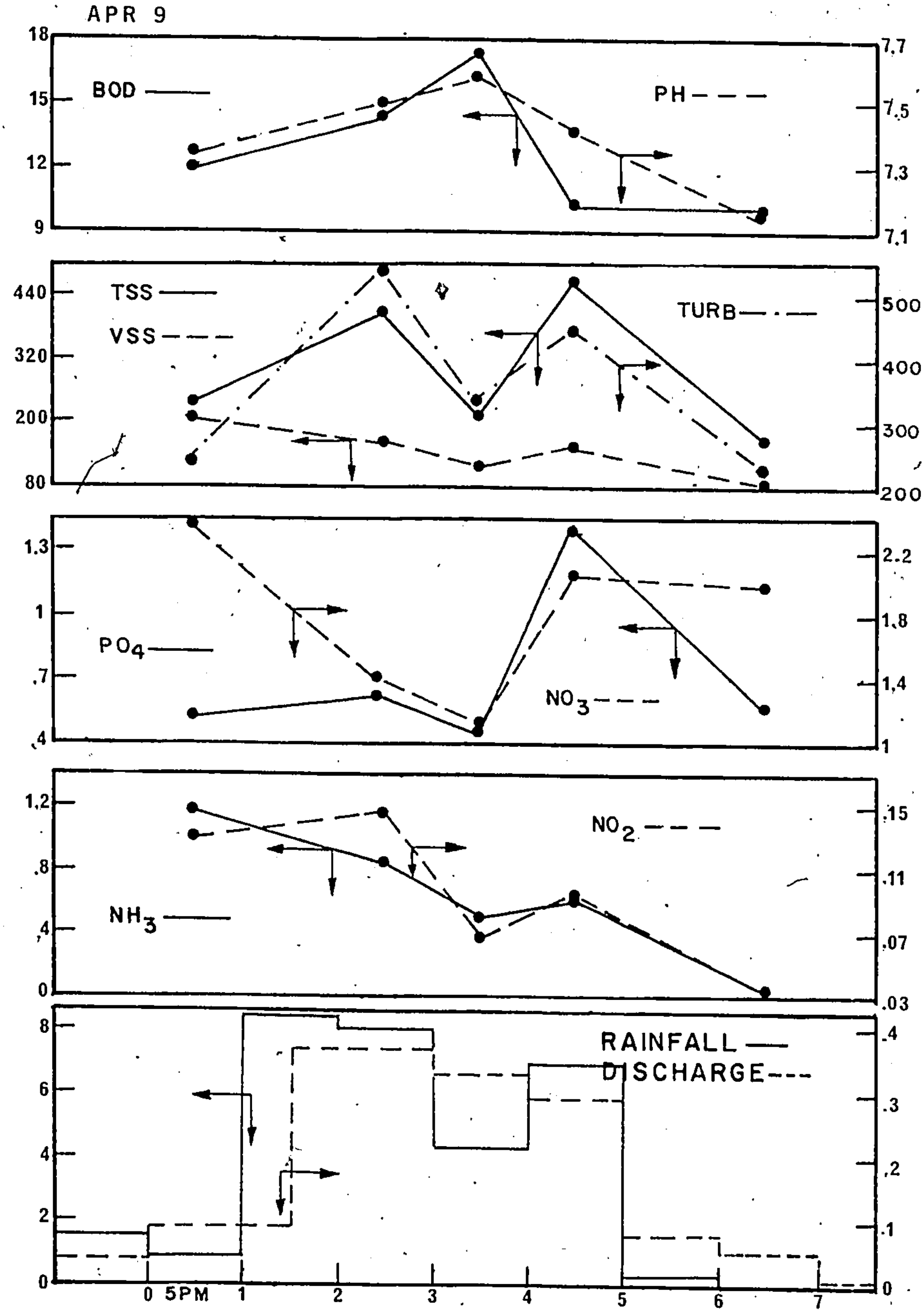

MAR 16 – 17
Cl
SO4
SP. CON.
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
115
95
75
55
35
15
.7
.56
.42
.28
.14
0
450
350
250
150
50
3
1
.1
7:15 PM
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19


MAR 29
BOD
PH
22
18
14
10
7.7
7.6
7.5
TURB
TSS
VSS
270
200
130
60
440
340
240
140
NO_3
PO_4
.9
.7
.5
.3
1.35
1.1
.85
.6
NO_2
NH_3
.75
.5
.25
0
.08
.06
.04
RAINFALL
DISCHARGE
20
15
10
5
0
.8
.6
.4
.2
0
0 5:30PM 1
2
3
4
5
6
7
8

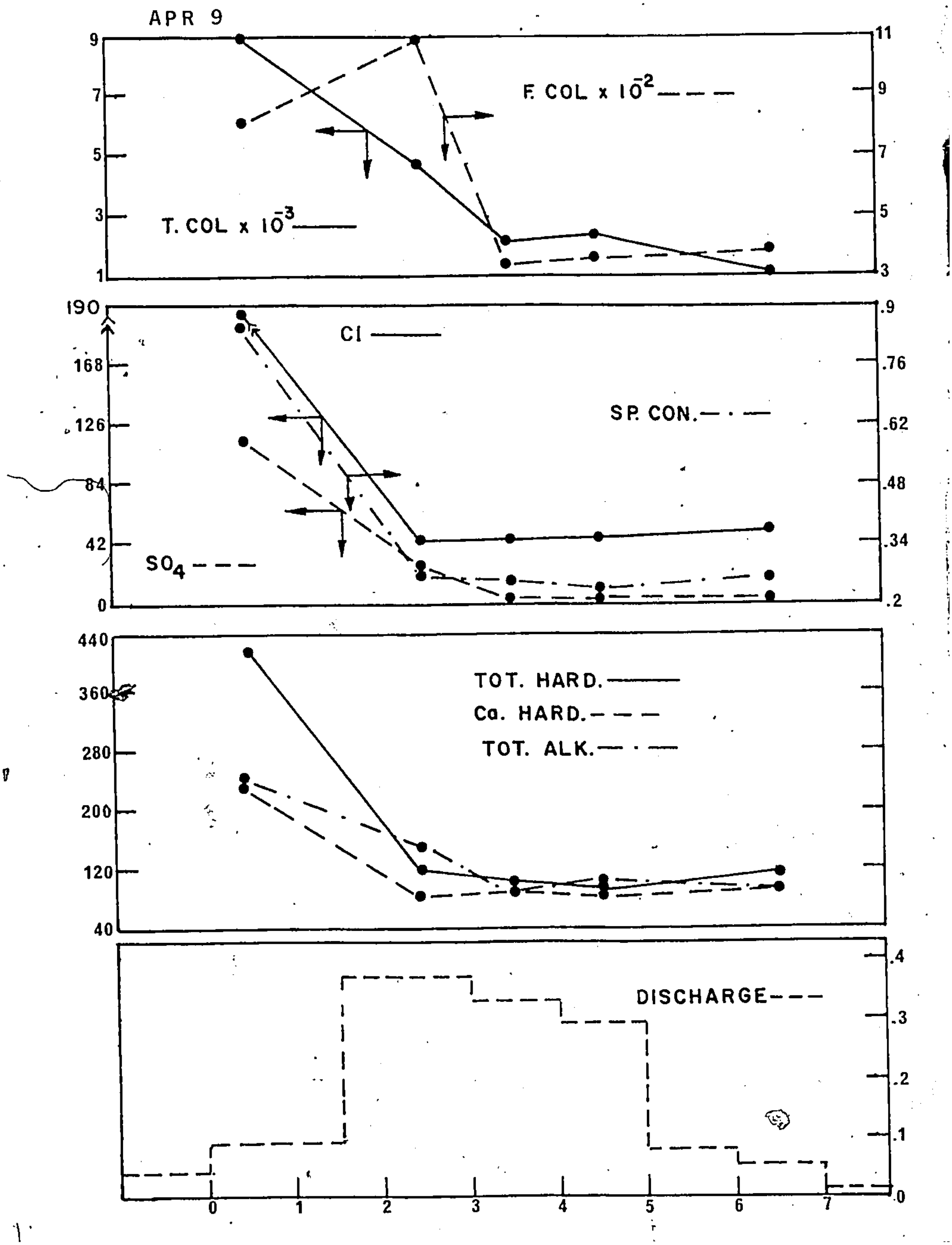

MAR 29
F. COL x 10⁻¹
T. COL x 10⁻²
133
18
13
8
1100
44
24
4
Cl
SP. CON.
SO4
145
120
95
70
45
20
.6
.5
.4
.3
.2
TOT. HARD.
Ca HARD.
TOT. ALK.
210
170
130
90
50
DISCHARGE
.8
.6
.4
.2
0
0
1
2
3
4
5
6
7
8


MAR 31
BOD
PH
26
18
10
2
7,8
7,6
7,4
T. COL x 10^-2
F.COL x 10^-1
17
13
9
5
19
13
7
1
NO3
PO4
1,74
.5
.3
.1
2.3
1,8
1,3
.8
NH3
NO2
1.76
.6
.3
0
.055
.035
.015
RAINFALL
DISCHARGE
9
6
3
0
3.2
2.4
1.6
.8
0
0
8 PM
1
2
3
4
5
6
7
8

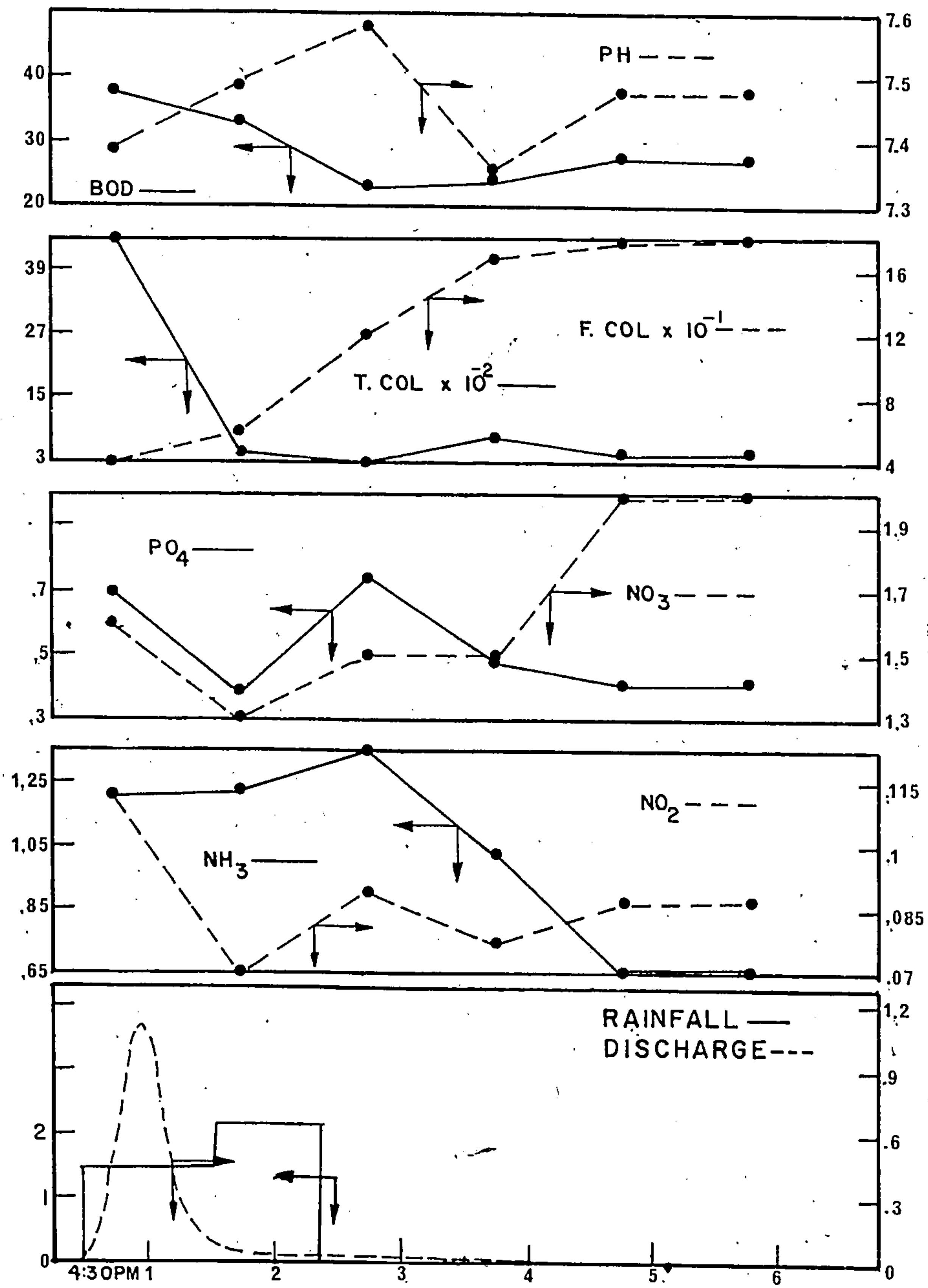

MAR 31
340
260
180
100
20
.98
.78
.58
.38
.18
Cl
SP. CON.
SO_4
TOT. HARD.
Ca. HARD.
TOT. ALK.
470
370
270
170
70
780
510
390
270
150
30
TSS
VSS
TURB
830
630
430
230
30
DISCHARGE
3.2
2.4
1.6
.8
0
0
1
2
3
4
5
6
7
8

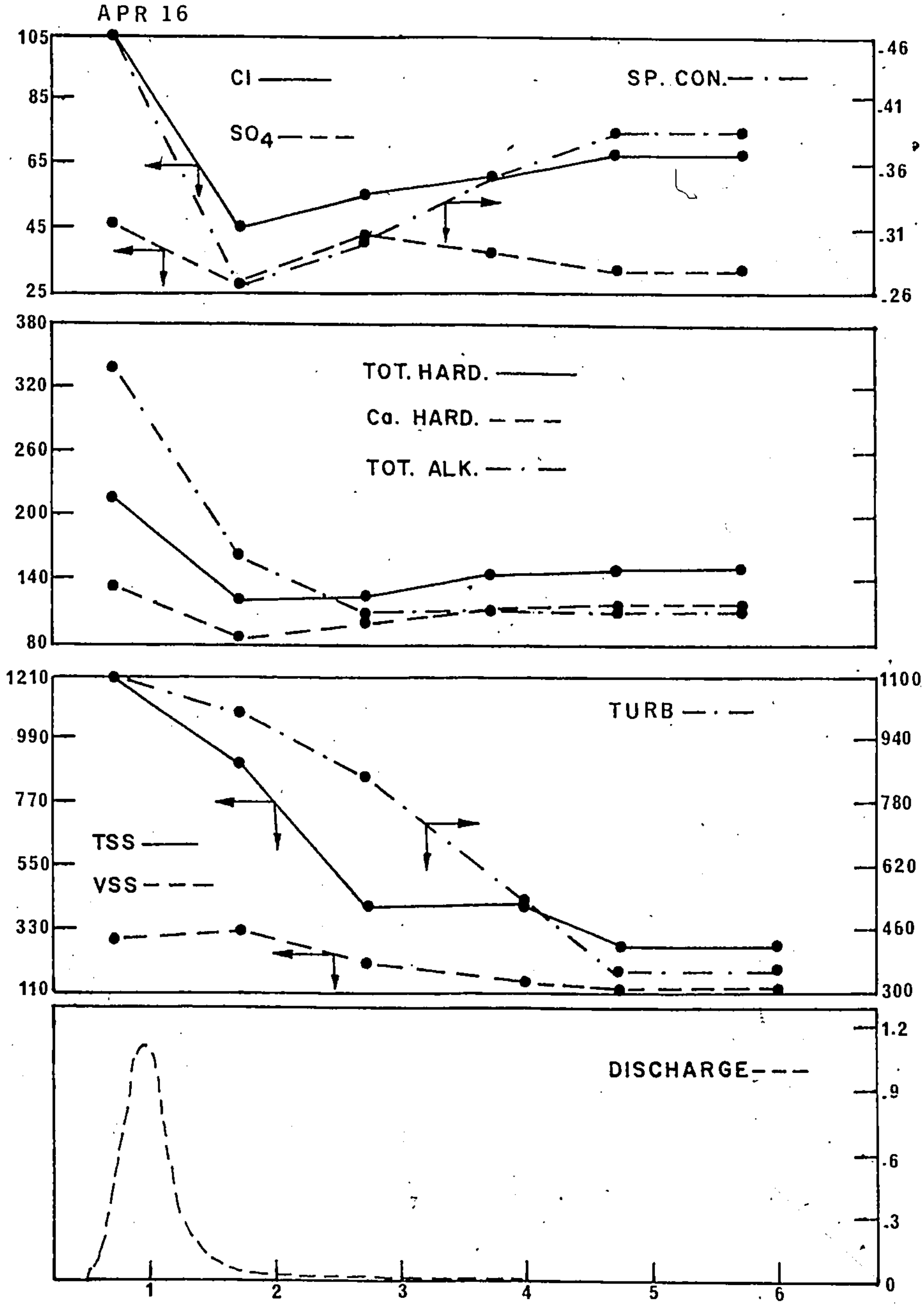


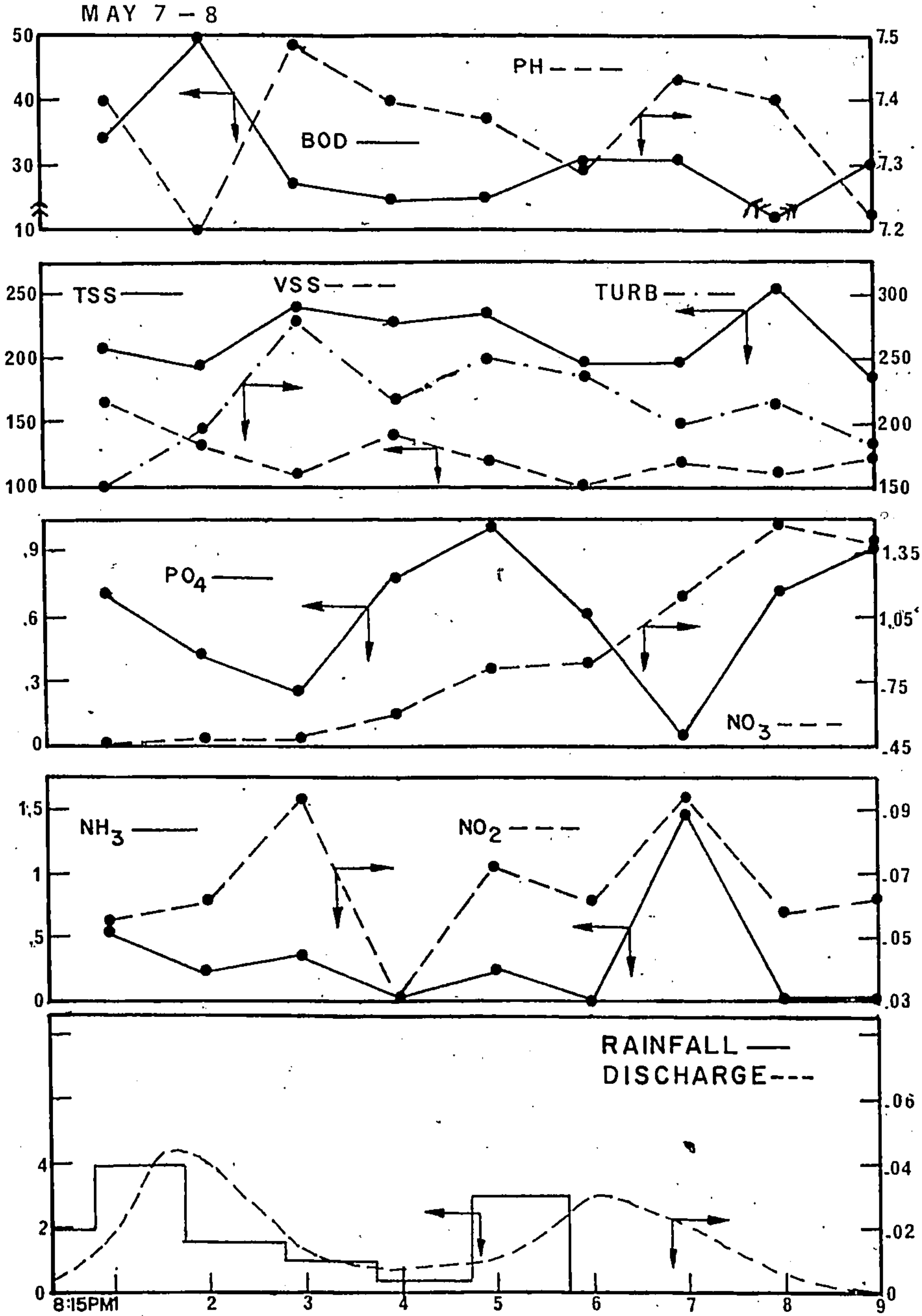
APR 9
BOD
PH
18
15
12
9
7.7
7.5
7.3
7.1
TSS
VSS
TURB
440
320
200
80
500
400
300
200
PO4
NO3
1.3
1
.7
.4
2.2
1.8
1.4
1
NO2
NH3
1.2
.8
.4
0
.15
.11
.07
.03
RAINFALL
DISCHARGE
8
6
4
2
0
.4
.3
.2
.1
0
0 5PM
1
2
3
4
5
6
7


APR 9
F. COL x 10^{-2}
T. COL x 10^{-3}
Cl
SP. CON.
SO_4
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
9 7 5 3 1
11 9 7 5 3
190 168 126 84 42 0
.9 .76 .62 .48 .34 .2
440 360 280 200 120 40
.4 .3 .2 .1 .0
0 1 2 3 4 5 6 7

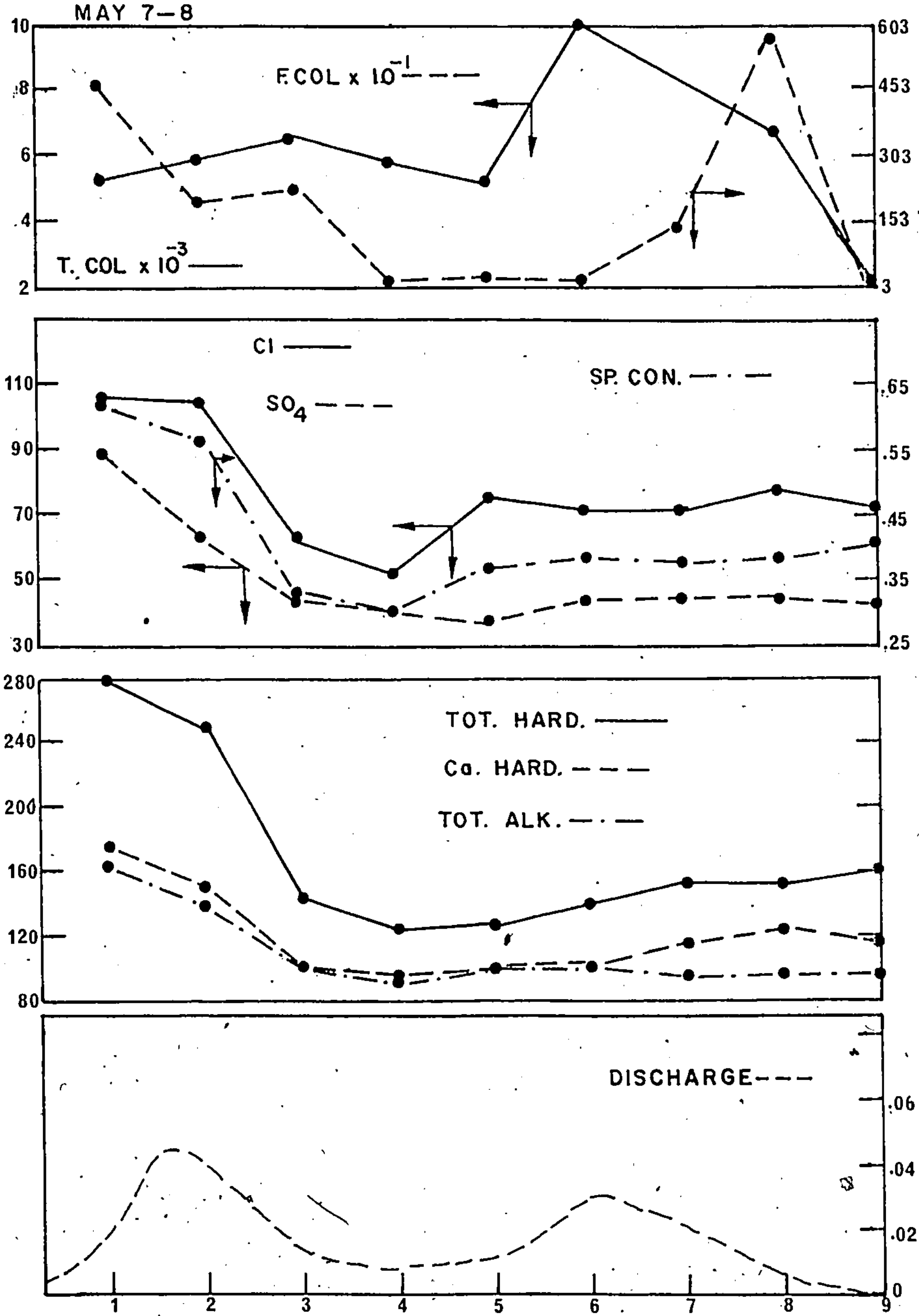
APR 16

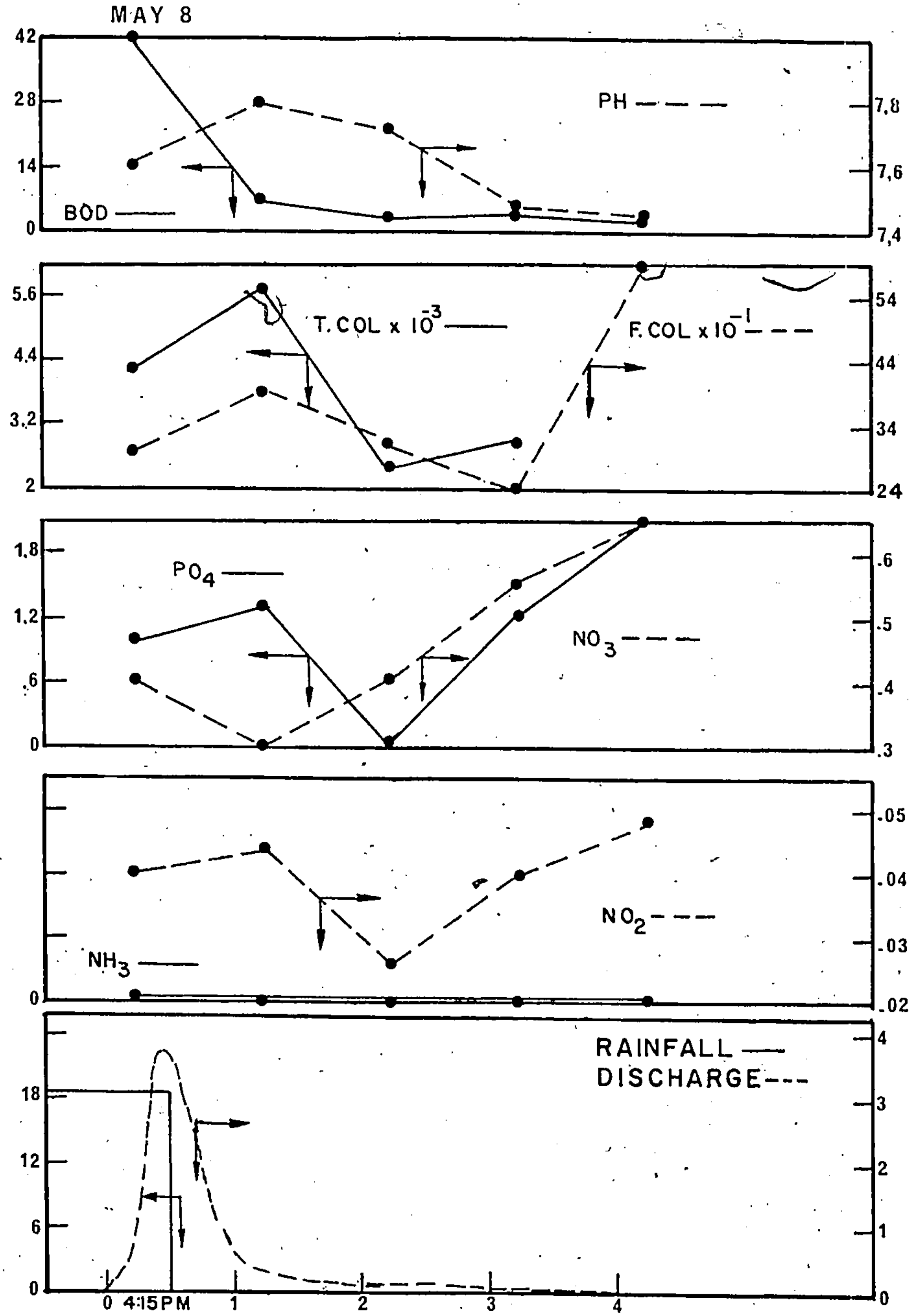

PH
BOD
40
30
20
7.6
7.5
7.4
7.3
F. COL x 10^{-1}
T. COL x 10^{-2}
39
27
15
3
16
12
8
4
PO_4
NO_3
.7
.5
.3
1.9
1.7
1.5
1.3
NO_2
NH_3
1.25
1.05
.85
.65
.115
.1
.085
.07
RAINFALL
DISCHARGE
2
1
0
1.2
.9
.6
.3
0
4:30PM 1
2
3
4
5
6

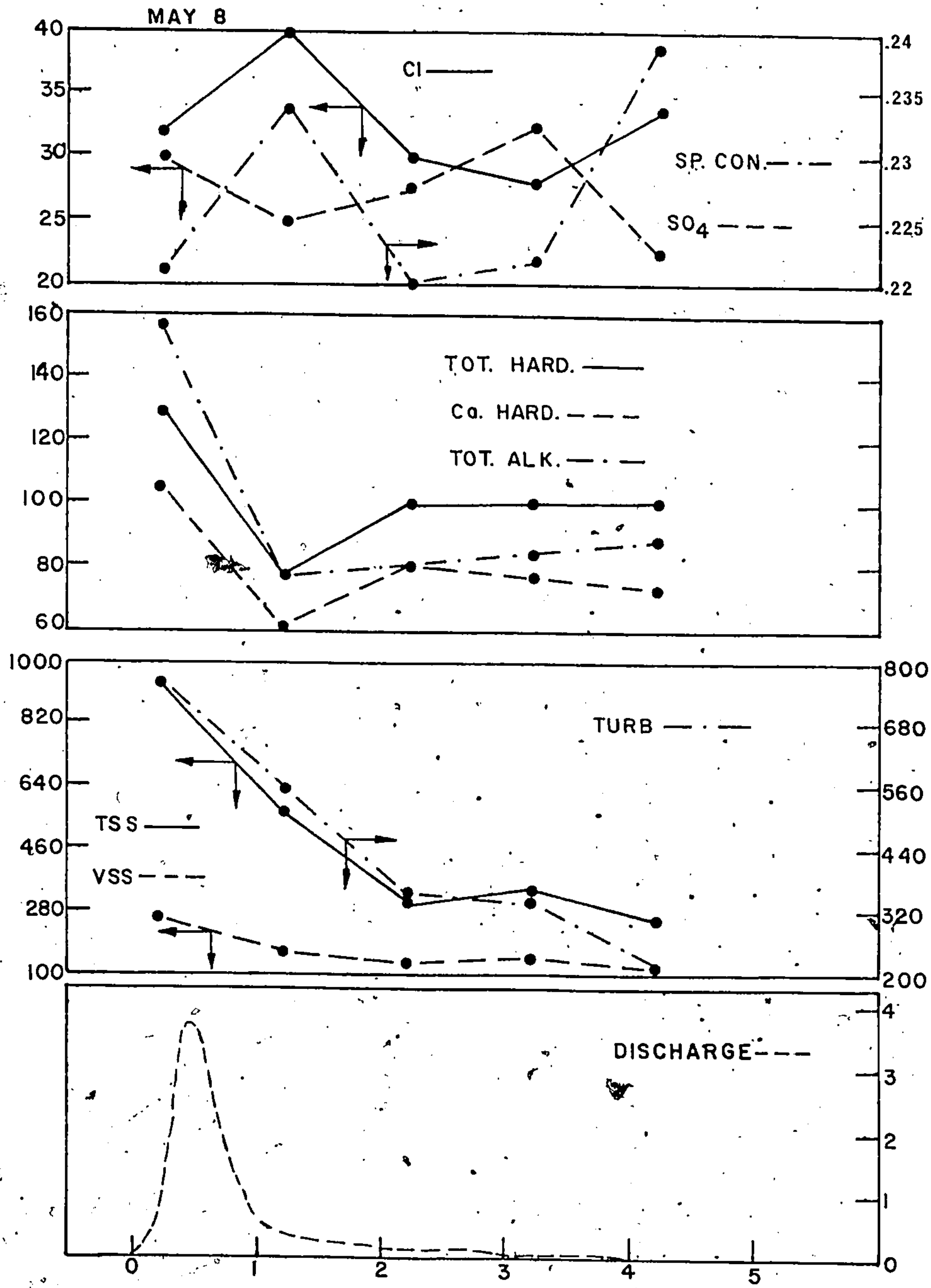

APR 16
105
85
65
45
25
.46
.41
.36
.31
.26
Cl
SO4
SP. CON.
380
320
260
200
140
80
TOT. HARD.
Ca. HARD.
TOT. ALK.
1210
990
770
550
330
110
1100
940
780
620
460
300
TURB
TSS
VSS
1.2
.9
.6
.3
0
DISCHARGE
1
2
3
4
5
6

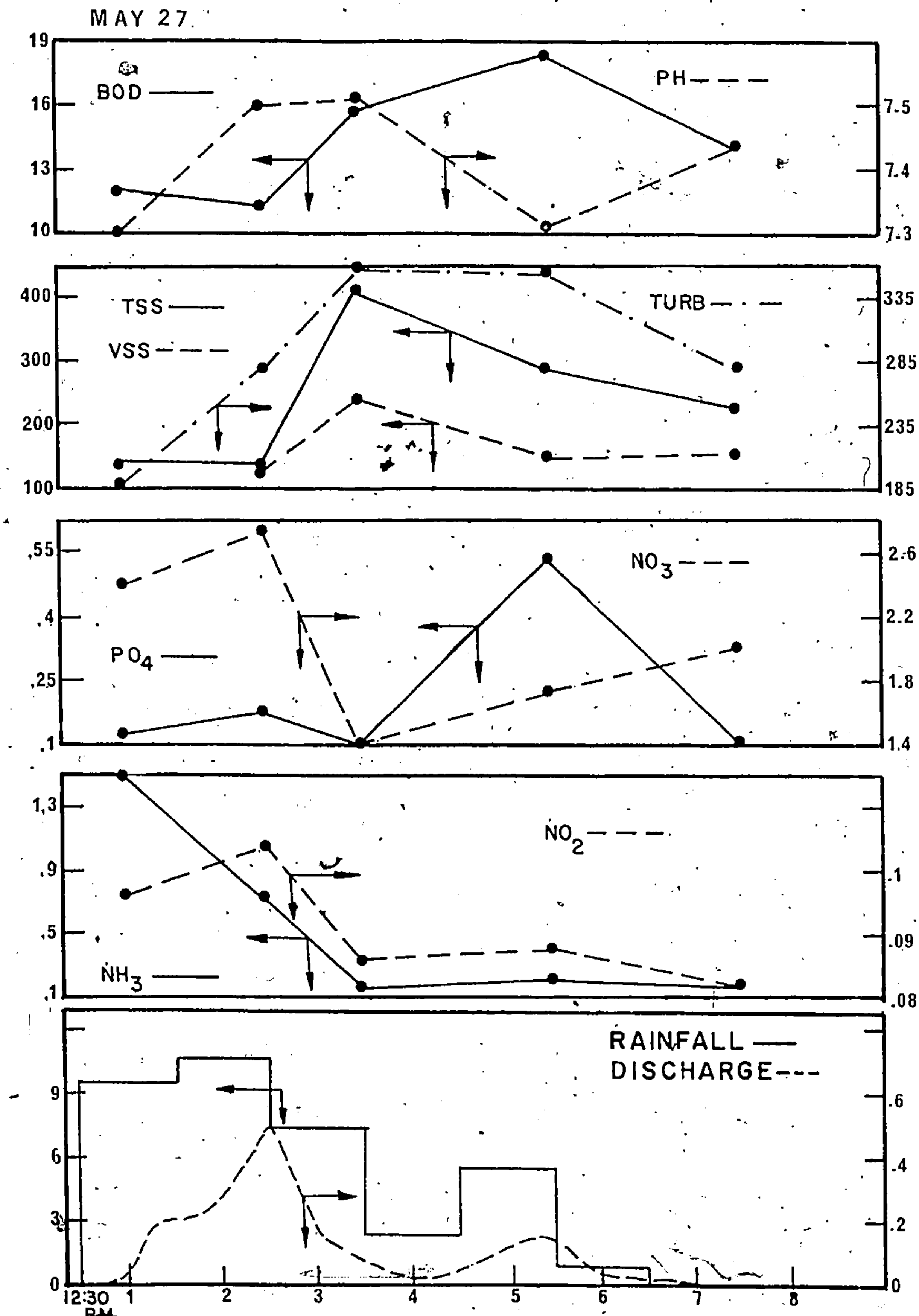


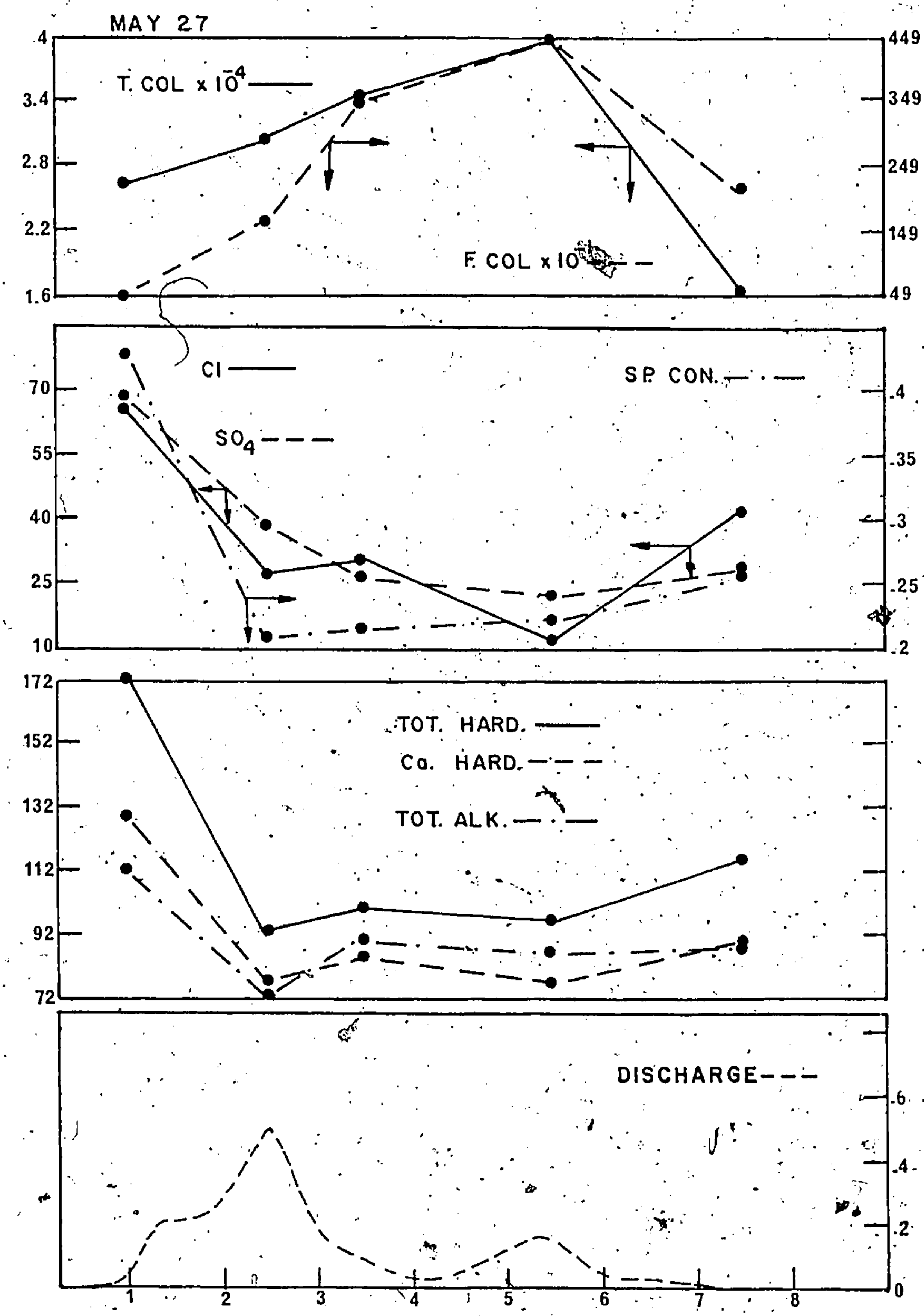
MAY 7 - 8
PH
BOD
TSS
VSS
TURB
PO4
NO3
NH3
NO2
RAINFALL
DISCHARGE
8:15PM

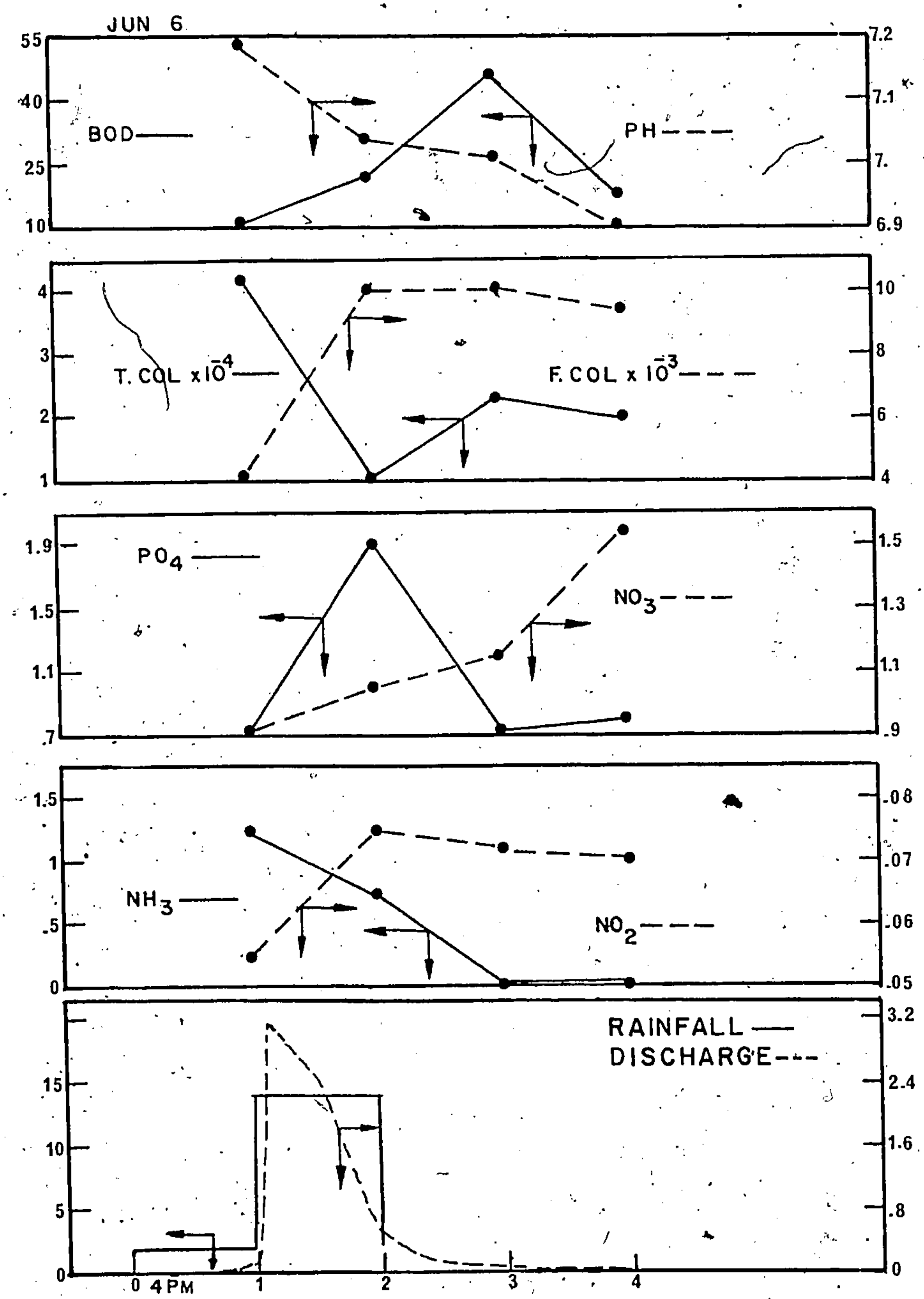

MAY 7—8
F.COL x 10^{-1}
T. COL x 10^{-3}
10
8
6
4
2
603
453
303
153
3
Cl
SO4
SP. CON.
110
90
70
50
30
.65
.55
.45
.35
.25
TOT. HARD.
Ca. HARD.
TOT. ALK.
280
240
200
160
120
80
DISCHARGE
.06
.04
.02
0
1
2
3
4
5
6
7
8
9

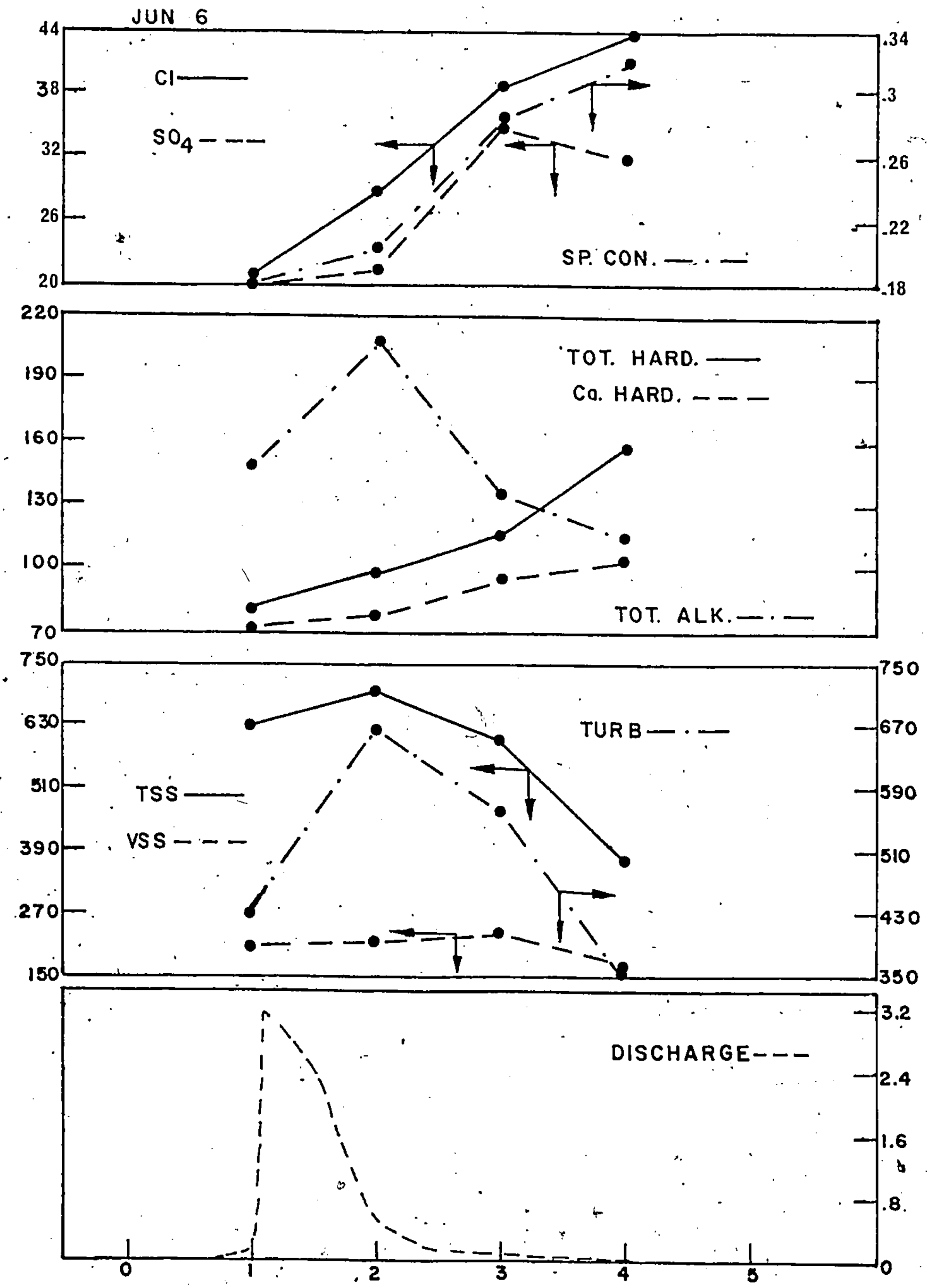

MAY 8
42
28
14
0
BOD
PH
7,8
7,6
7,4
5.6
4.4
3.2
2
T. COL x 10^-3
F. COL x 10^-1
54
44
34
24
1.8
1.2
.6
0
PO4
NO3
.6
.5
.4
.3
NH3
0
NO2
.05
.04
.03
.02
RAINFALL
DISCHARGE
18
12
6
0
4
3
2
1
0
0 4:15PM
1
2
3
4

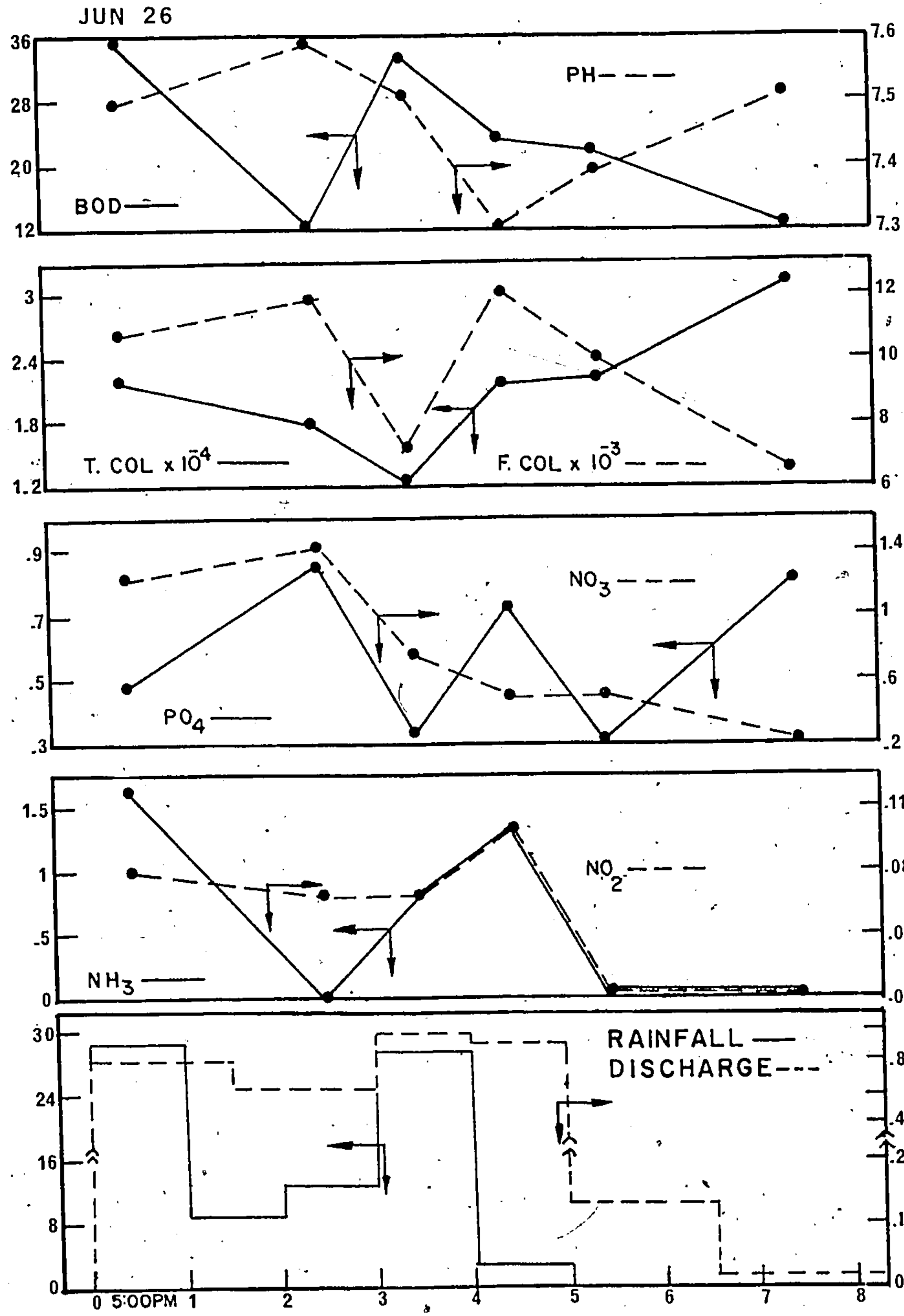

MAY 8
40
35
30
25
20
.24
.235
.23
.225
.22
Cl
SP. CON.
SO4
160
140
120
100
80
60
TOT. HARD.
Ca. HARD.
TOT. ALK.
1000
820
640
460
280
100
800
680
560
440
320
200
TURB
TSS
VSS
DISCHARGE
4
3
2
1
0
0
1
2
3
4
5

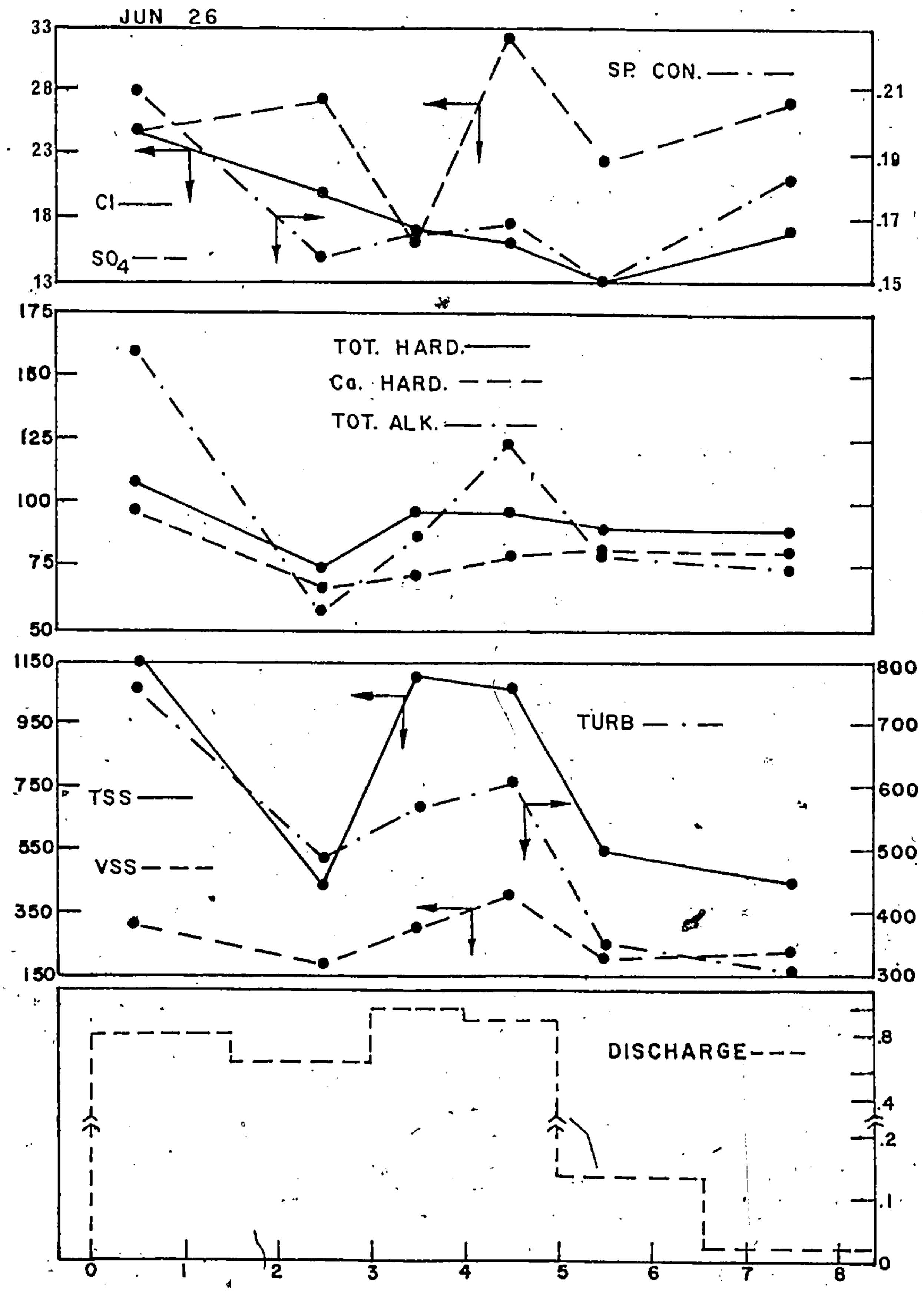

MAY 27
BOD
PH
19
16
13
10
7.5
7.4
7.3
TSS
VSS
TURB
400
300
200
100
335
285
235
185
NO3
PO4
.55
.4
.25
.1
2.6
2.2
1.8
1.4
NO2
NH3
1.3
.9
.5
.1
.1
.09
.08
RAINFALL
DISCHARGE
9
6
3
0
.6
.4
.2
0
12:30 PM
1
2
3
4
5
6
7
8


MAY 27
T. COL x 10^{-4}
F. COL x 10^{-1}
Cl
SP. CON.
SO_4
TOT. HARD.
Ca. HARD.
TOT. ALK.
DISCHARGE
.4
3.4
2.8
2.2
1.6
449
349
249
149
49
70
55
40
25
10
.4
.35
.3
.25
.2
172
152
132
112
92
72
.6
.4
.2
0
1
2
3
4
5
6
7
8

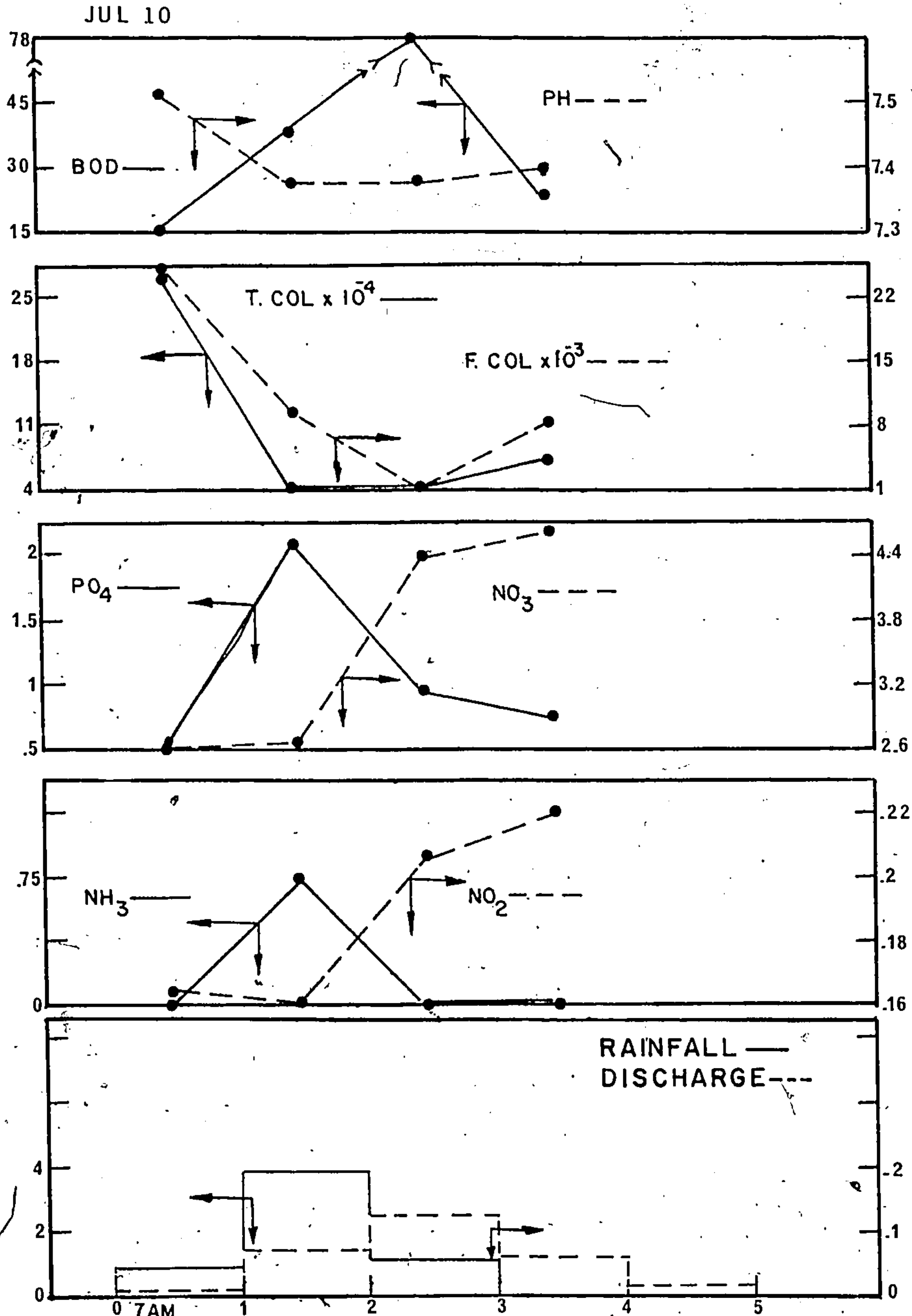

JUN 6
BOD
PH
55
40
25
10
7.2
7.1
7.
6.9
T. COL x 10^{-4}
F. COL x 10^{-3}
4
3
2
1
10
8
6
4
PO_4
NO_3
1.9
1.5
1.1
.7
1.5
1.3
1.1
.9
NH_3
NO_2
1.5
1
.5
0
.08
.07
.06
.05
RAINFALL
DISCHARGE
15
10
5
0
3.2
2.4
1.6
.8
0
0 4PM
1
2
3
4

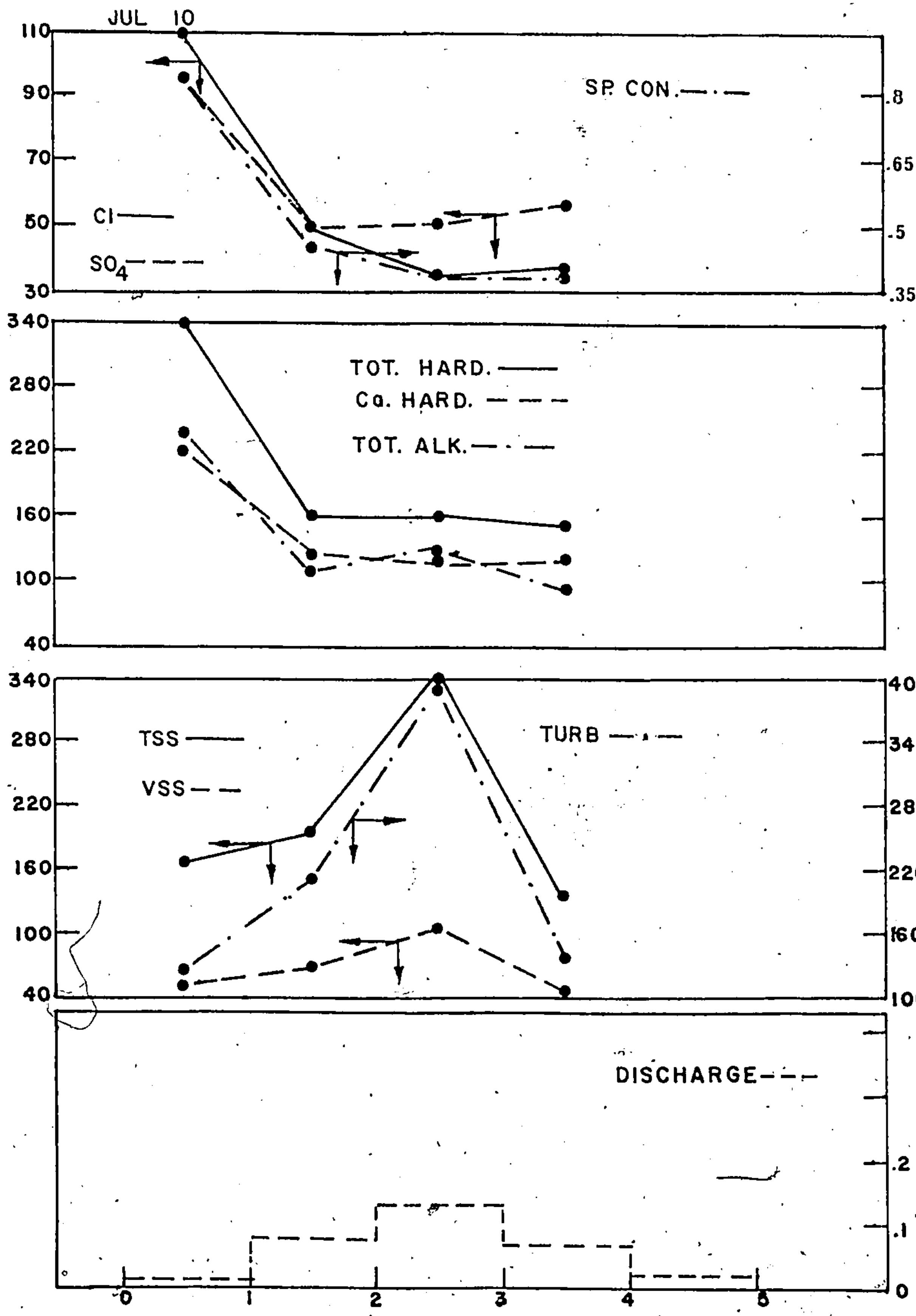

JUN 6
Cl
SO4
SP. CON.
TOT. HARD.
Ca. HARD.
TOT. ALK.
TURB
TSS
VSS
DISCHARGE
44
38
32
26
20
.34
.3
.26
.22
.18
220
190
160
130
100
70
750
630
510
390
270
150
750
670
590
510
430
350
3.2
2.4
1.6
.8
0
0
1
2
3
4
5

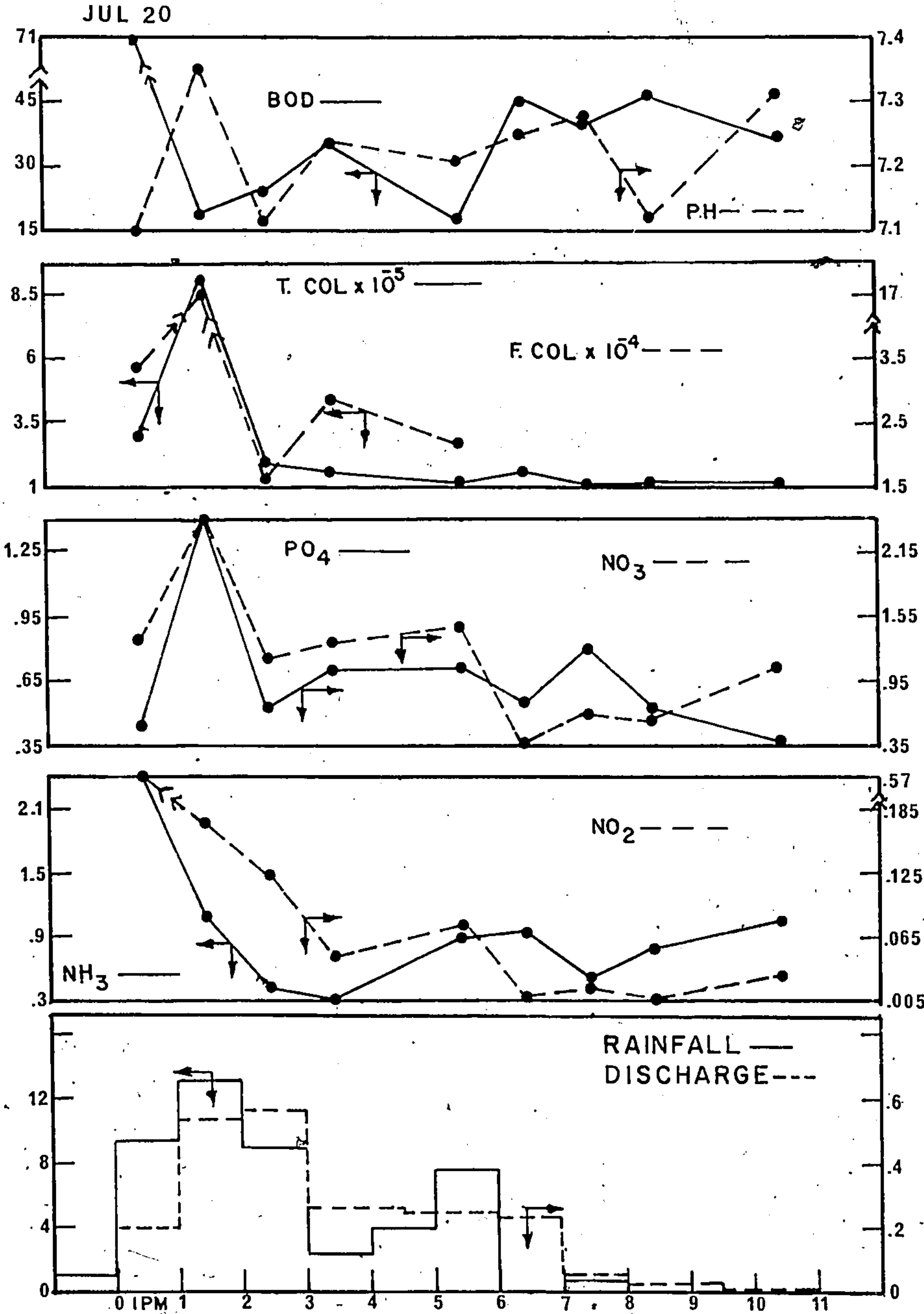

JUN 26
36
28
20
12
BOD
PH
7.6
7.5
7.4
7.3
3
2.4
1.8
1.2
T. COL x 10^{-4}
F. COL x 10^{-3}
12
10
8
6
.9
.7
.5
.3
PO_4
NO_3
1.4
1
.6
.2
1.5
1
.5
0
NH_3
NO_2
.11
.08
.05
.02
30
24
16
8
0
RAINFALL
DISCHARGE
.8
.4
.2
.1
0
0 5:00PM 1
2
3
4
5
6
7
8

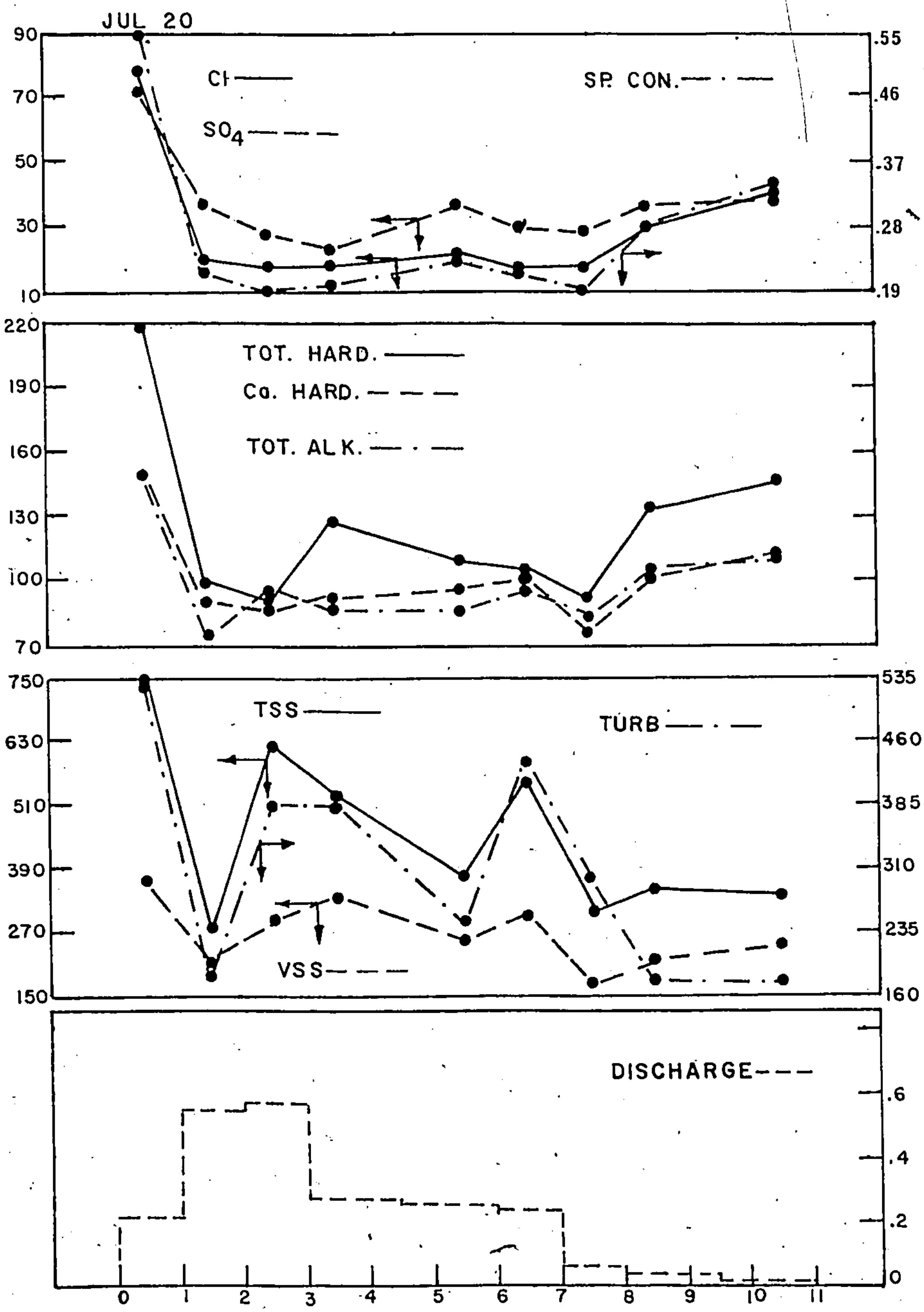


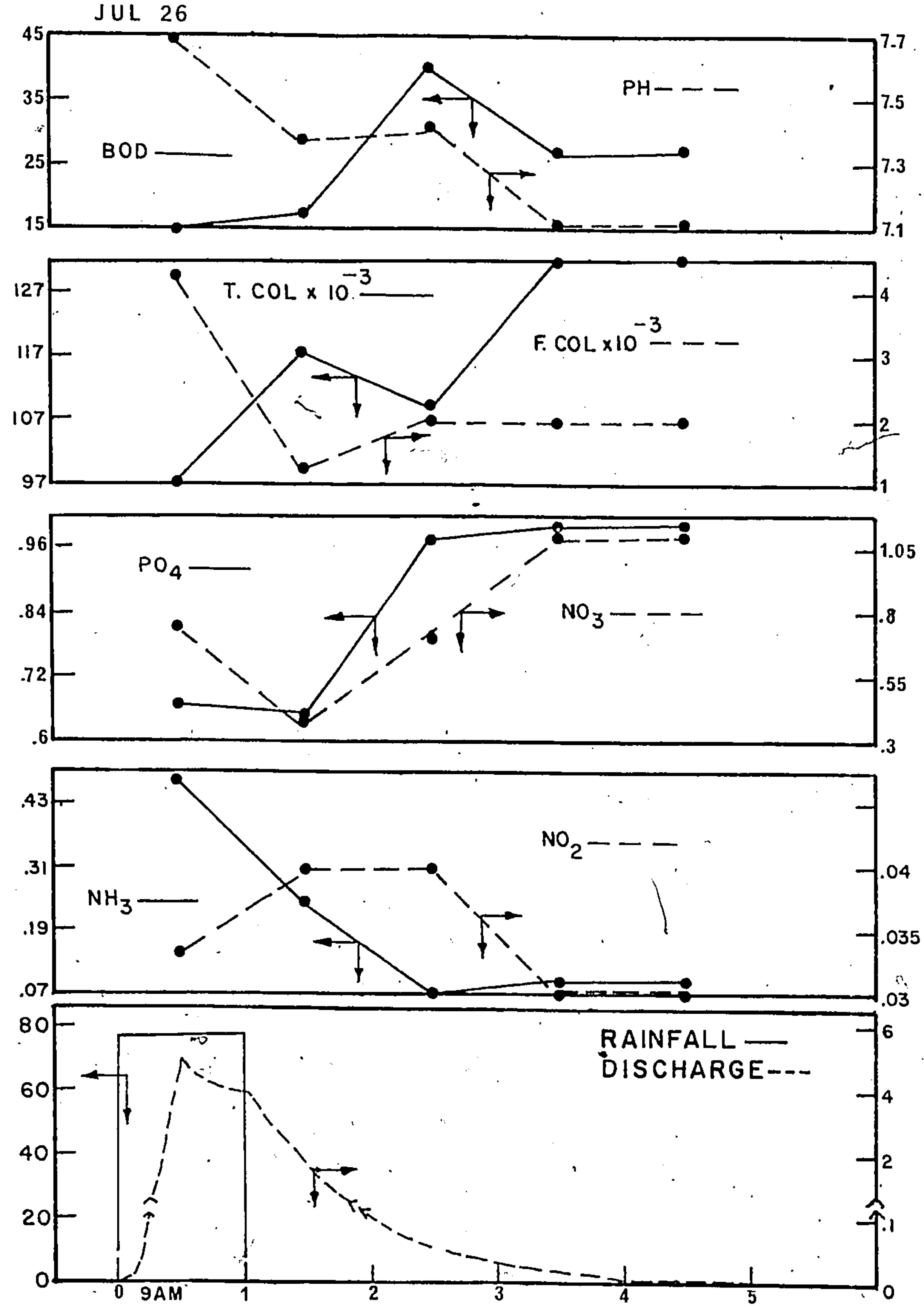
JUN 26
SP. CON.
Cl
SO_4
TOT. HARD.
Ca. HARD.
TOT. ALK.
TURB
TSS
VSS
DISCHARGE

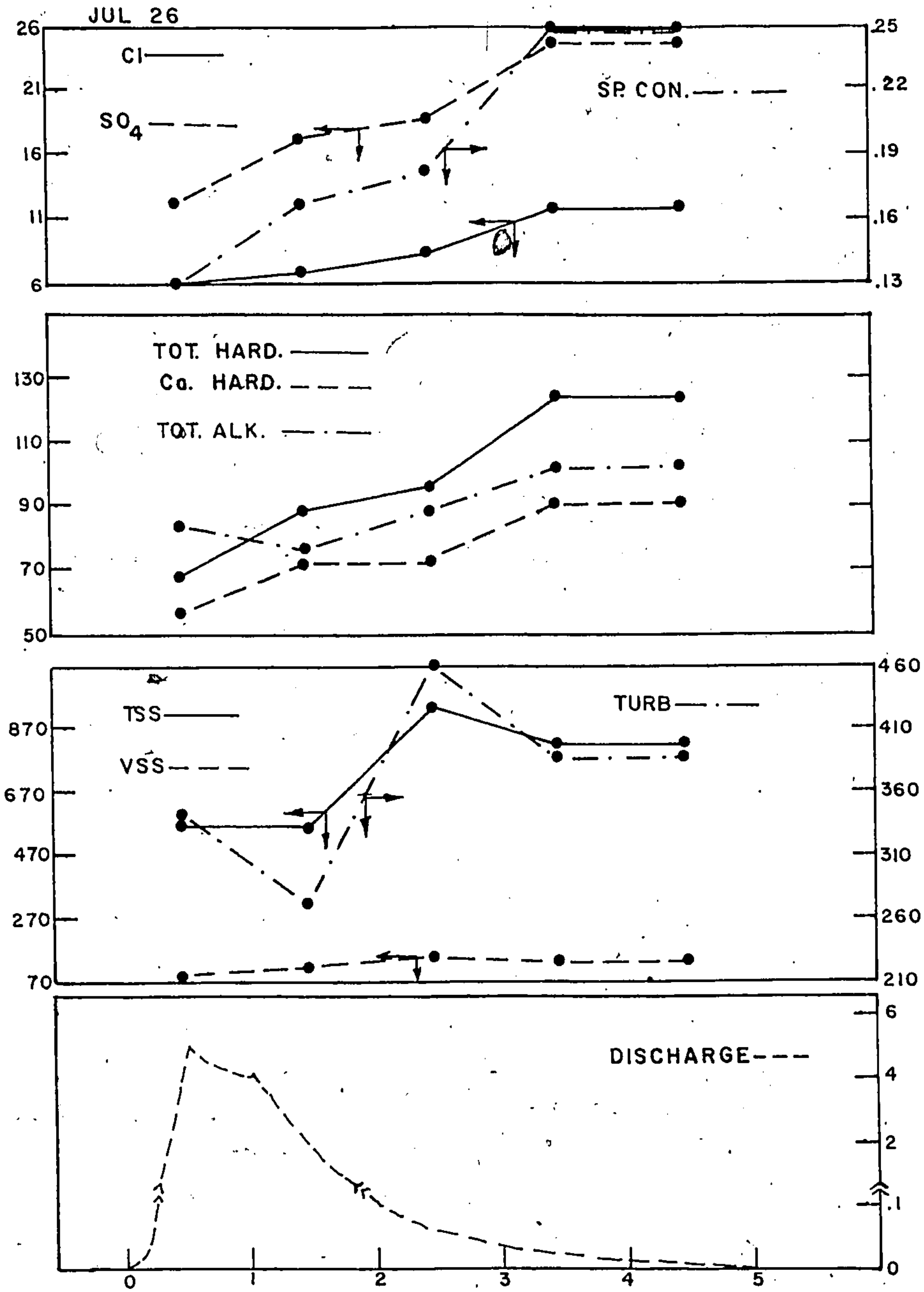

JUL 10
78
45
30
15
BOD
PH
7.5
7.4
7.3
25
18
11
4
T. COL x 10⁻⁴
F. COL x 10⁻³
22
15
8
1
2
1.5
1
.5
PO4
NO3
4.4
3.8
3.2
2.6
.75
0
NH3
NO2
.22
.2
.18
.16
RAINFALL
DISCHARGE
4
2
0
.2
.1
0
0 7AM
1
2
3
4
5

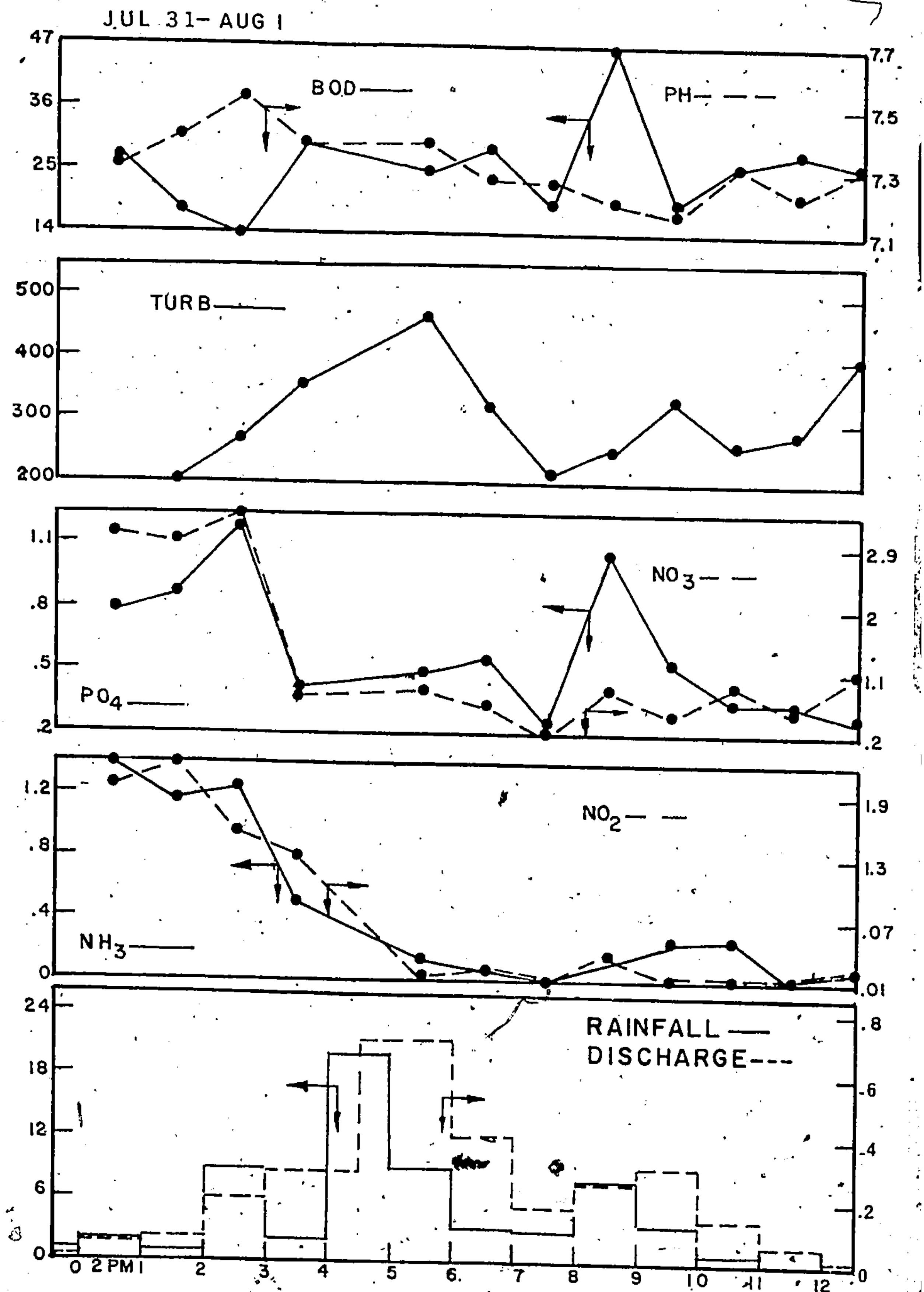

JUL 10
SP. CON.
Cl
SO4
TOT. HARD.
Ca. HARD.
TOT. ALK.
TSS
VSS
TURB
DISCHARGE
110
90
70
50
30
.8
.65
.5
.35
340
280
220
160
100
40
340
280
220
160
100
40
400
340
280
220
160
100
.2
.1
0
0
1
2
3
4
5

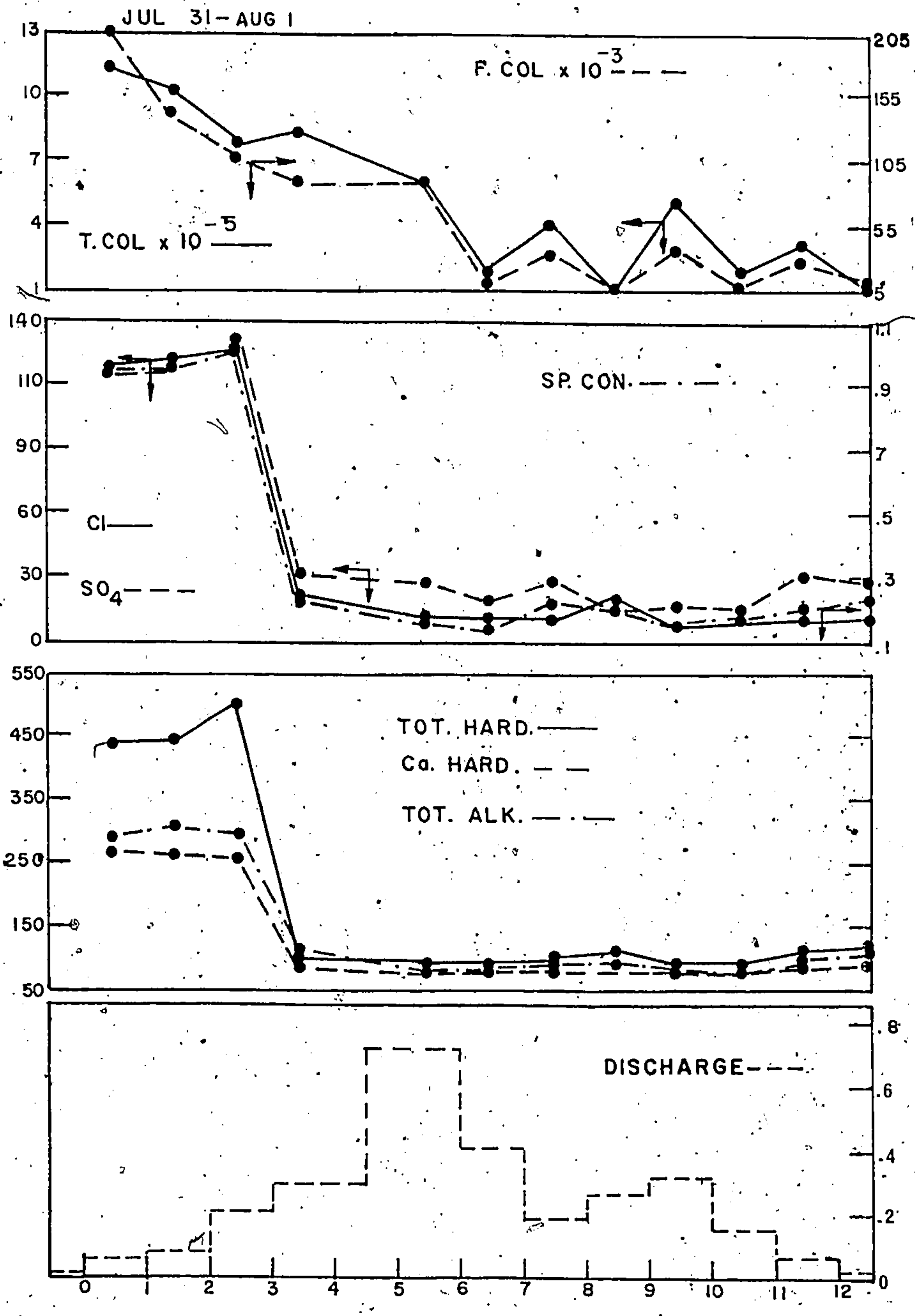

JUL 20
BOD
PH
T. COL x 10^{-5}
F. COL x 10^{-4}
PO_4
NO_3
NO_2
NH_3
RAINFALL
DISCHARGE
0 1PM 1 2 3 4 5 6 7 8 9 10 11


JUL 20
Cl
SO4
SP. CON.
90
70
50
30
10
.55
.46
.37
.28
.19
TOT. HARD.
Ca. HARD.
TOT. ALK.
220
190
160
130
100
70
TSS
TURB
VSS
750
630
510
390
270
150
535
460
385
310
235
160
DISCHARGE
.6
.4
.2
0
0
1
2
3
4
5
6
7
8
9
10
11


JUL 26
45
35
25
15
7.7
7.5
7.3
7.1
PH
BOD
127
117
107
97
4
3
2
1
T. COL x 10^-3
F. COL x 10^-3
.96
.84
.72
.6
1.05
.8
.55
.3
PO4
NO3
.43
.31
.19
.07
.04
.035
.03
NO2
NH3
80
60
40
20
0
6
4
2
.1
0
RAINFALL
DISCHARGE
0
9AM
1
2
3
4
5


JUL 26
Cl
SO4
SP. CON.
26
21
16
11
6
.25
.22
.19
.16
.13
TOT. HARD.
Ca. HARD.
TOT. ALK.
130
110
90
70
50
TSS
VSS
TURB
870
670
470
270
70
460
410
360
310
260
210
DISCHARGE
6
4
2
.1
0
0
1
2
3
4
5


JUL 31- AUG 1
BOD
PH
TURB
NO3
PO4
NO2
NH3
RAINFALL
DISCHARGE
0 2PM 1
2
3
4
5
6
7
8
9
10
11
12


JUL 31 – AUG 1
F. COL x 10^{-3}
T. COL x 10^{-5}
13
10
7
4
1
205
155
105
55
5
SP. CON.
Cl
SO_4
140
110
90
60
30
0
1.1
.9
.7
.5
.3
.1
TOT. HARD.
Ca. HARD.
TOT. ALK.
550
450
350
250
150
50
DISCHARGE
.8
.6
.4
.2
0
0
1
2
3
4
5
6
7
8
9
10
11
12

APPENDIX B

ADDITIONAL INFORMATION ON THE STORMS

In the Table below, the amount of precipitation in the last previous precipitation event of 0.076 cm. (0.03 in.) or more was calculated as the average of readings of gauges E-4, E-11 and E-13 (sec. 3.3). If one or two of these gauges did not function, the remaining gauge(s) only were used. See Table 3-4 for the time period between a storm and the last precipitation event of 0.076 cm. or more.

TABLE B-1

OTHER DATA PERTAINING TO THE STORMS

Storm No.	Amount of Precipitation (cm.) in Preceding Event of 0.076 cm. or more	Intensity (cm./hr.) of Preceding Event of 0.076 cm. or more
1	1.96	0.49
2	0.11	0.06
3	0.08	0.04
4	0.94	0.12
5	0.25	0.06
6	0.25	0.13
7	0.15	0.08
8	0.18	0.04
9	0.50	0.07
10	0.18	0.04
11	0.19	0.05
12	1.47	0.25
13	0.10	0.03
14	1.31	0.26
15	----	----
16	0.49	0.08
17	0.48	0.48
18	0.40	0.04
19	0.71	0.06
20	0.59	0.59
21	0.09	0.09
22	3.00	1.00
23	0.23	0.08
24	1.30	0.19
25	1.92	0.96

APPENDIX C

THE ROAD RESEARCH LABORATORY PROGRAM FOR RUNOFF

```
C       RRL HYDROGRAPH
C THIS PROGRAM IS FOR CALCULATING THE RUNOFF HYDROGRAPH
C BY THE ROAD RESEARCH LABORATORY (RRL) METHOD
C THIS PROGRAM USES AND CALCULATES  QUANTITIES IN
C ENGLISH UNITS.  E. G. CUBIC FEET, CFS AND INCHES.
      DIMENSION A(6), S(420)
      DIMENSION AFLOW(35)
      DIMENSION R(420)
      DIMENSION RAIN(35), Q(420), VIRT(420), Z(420), CALCA(420,6)
      INTEGER*2 TIME(420)
      L = 1
C  T IS THE TIME INTERVAL IN MINUTES.
  101 READ 62, T
   62 FORMAT(3X,F3.1)
C         THE RUNOFF COEFFICIENT IS R
      READ 70, R
   70 FORMAT(F5.3)
C    THE IMPERVIOUS AREAS ARE A(1) THROUGH A(6)
      READ 63, A
   63 FORMAT(6F6.2)
C RAIN IS IN HUNDREDTHS OF AN INCH.
      READ 64, RAIN
   64 FORMAT(16F5.1,/,16F5.1,/,3F5.1)
      C = 36.3*R
      DO 50 I = 1,35
      M = 12*I
      N = (I-1)*12 + 1
      DO 50 J = N,M
      R(J) = RAIN(I)/12.
   50 CONTINUE
      DO 4 I= 1, 420
      DO 4 J = 1, 6
      K = (I-(J-1))
      IF (K) 5,5,6
    5 CALCA(I,J) = 0
      GO TO 4
    6 CALCA(I,J) = C*R(K)*A(J)
    4 CONTINUE
      DO 8 I = 1, 420,
      SUM = 0
      DO 9 J = 1, 6
    9 SUM = SUM + CALCA(I,J)
    8 VIRT(I) = SUM/300.
      TIME(1) = 10
      DO 10 I = 2, 420
   10 TIME(I) = TIME((I-1)) + T
```

```
C  Q(I) IS AVERAGE DISCHARGE IN TIME INTERVAL T.
   12 Q(1) = VIRT(1)/19.67
C  S(I) IS THE STORAGE-DISCHARGE FUNCTION.
      S(1) = 2800*Q(1)
   14 DO 15 I = 2, 420
      Z(I) = VIRT((I-1)) + VIRT(I) - Q((I-1)) + S((I-1))/150.
      IF (Z(I) - .001)16,16,17
   16 Q(I) = 0
      S(I) = 0
      GO TO 15
   17 IF (Z(I) - 2.563)18,18,19
   18 Q(I) = Z(I)/19.67
      S(I) = 2800*Q(I)
      GO TO 15
   19 Q(I) = (Z(I)/9.50) - .14
      S(I) = 200. + (1275*Q(I))
   15 CONTINUE
      DO 21 I = 1,35
      K = 12*I - 11
C  AFLOW IS THE AVERAGE HOURLY DISCHARGE.
      AFLOW(I) = (Q(K)+Q(K+1)+Q(K+2)+Q(K+3)+Q(K+4)+Q(K+5)+Q(K+6)+Q(K+7)
     X +Q(K+8)+Q(K+9)+Q(K+10)+Q(K+11))/12
   21 CONTINUE
      DO 22 I = 1,140
      J = I + 140
      K = I + 280
   22 PRINT 23, I,S(I), Q(I), TIME(I), J, S(J), Q(J), TIME(J),
     X  K, S(K), Q(K), TIME(K)
   23 FORMAT(' ',I3,F7.0,F7.3,I6,6X,I3,F7.0,F7.3,I6,6X,I3,F7.0,F7.3,
     X I6)
      PRINT 24, AFLOW
   24 FORMAT('-',10F7.3,/,1X,10F7.3,/,1X,5F7.3)
      L = L + 1
      IF (L-9)101,101,102
  102 STOP
      END
```

APPENDIX D

LISTING OF DATA USED IN THIS STUDY

In this appendix BOD, TSS, VSS, Ammonia-N, nitrate-N, nitrite-N, orthophosphates, chlorides, sulfates, total alkalinity (T. Alkalinity) as $CaCO_3$, calcium hardness (Ca. Hardness) as $CaCO_3$, and total hardness (T. Hardness) as $CaCO_3$ are listed in mg/ℓ. Total coliform and fecal coliform (F. Coliform) are listed in #/100 ml. Turbidity is listed in JTU. Specific conductance (S. Conductance) is listed in milli mhos/cm. Colour is listed in colour units. Discharge is listed in ft^3/sec.*. The weight is the number of hours over which the average discharge was taken. Refer to Appendix A for plots of all values except colour.

---

*multiply by 28.3 for ℓ/sec.

STORM	HR	BOD	TOTAL COLIFORM	F. COLIFORM	TSS	VSS	AMMONIA	NITRATE	NITRITE	ORTHO PO4	CHLORIDE	SULFATE	T. ALKALINITY	CA. HARDNESS	T. HARDNESS	PH	COLOUR	TURBIDITY	S. CONDUCTANCE	DISCHARGE	WEIGHT
1	1	22.4	41000	1000	92	56	0.095	0.7	0.440	0.080	36	38	96	105	150	6.90			0.271	0.186	1.0
1	2	12.8	17000	1500	160	92	0.012	1.4	0.013	0.060	11	14	64	70	85	6.75			0.134	1.107	1.0
1	3	15.5	31000	500	96	50	0.016	0.8	0.001	0.060	6	12	48	50	70	7.05			0.088	0.700	1.0
1	4	6.2	16000	200	80	60	0.008	0.2	0.002	0.100	5	10	56	45	65	6.95			0.081	0.030	1.5
1	6	7.4	5800	50	40	40	0.008	0.1	0.001	0.080	8	18	56	48	65	6.95			0.114	0.001	2.0
1	9	7.1	32000	160	48	48	0.023	0.6	0.002	0.100	13	25	76	65	85	7.00			0.161	0.001	1.0
1	10	3.9	24000	200	34	24	0.016	0.8	0.002	0.128	14	26	68	70	110	7.20			0.180	0.001	1.0
1	11	2.9	28000	230	50	40	0.023	0.8	0.001	0.084	17	25	80	70	110	7.20			0.212	0.001	1.0
2	1	8.0	17000	5500	297	13	0.042	0.4	0.008	0.025	6	17	64	60	83	7.70			0.112	0.676	1.0
2	2	3.5	13000	4200	438	70	0.036	0.3	0.005	0.008	5	18	54	55	70	7.68			0.076	0.908	1.5
2	4	1.7	12000	4800	281	20	0.060	1.0	0.002	0.095	5	25	50	55	70	7.70			0.078	0.557	1.5
2	5	2.6	14000	700	133	33	0.016	0.6	0.008	0.100	8	18	52	60	75	7.50			0.115	0.006	1.0
3	5	48.4	6[illegible]000	2200	280	43	0.110	0.2	0.023	1.260	18	18	90	60	93	7.21			0.116	0.386	0.0
3	6	48.4	38000	3800	117	43	0.710	0.2	0.095	1.900	90	47	210	155	260	7.48			0.660	0.189	0.0
3	7	36.0	12000	550	77	77	0.128	0.2	0.020	0.200	16	14	70	55	80	7.49			0.117	0.128	0.0
3	8	7.1	39000	250	51	9	0.052	0.6	0.013	0.500	16	9	53	60	73	7.30			0.117	0.064	0.0
4	3	21.9	60000	3400	125	106	0.052	0.4	0.013	0.320	12	8	50	45	65	7.45			0.111	0.263	4.0
4	6	23.0	82000	750	86	29	0.020	0.5	0.003	0.360	13	7	68	55	70	7.49			0.131	0.250	1.0
4	7	23.9	85000	400	63	26	0.052	1.2	0.015	0.200	8	5	56	55	75	7.47			0.111	0.216	1.0
4	8	15.8	32000	500	100	46	0.038	1.2	0.020	0.220	10	4	58	55	78	7.49			0.124	0.220	1.0
4	9	18.6	63000	600	72	23	0.020	0.8	0.038	0.120	10	4	58	58	73	7.48			0.124	0.245	1.0
4	10	11.5	82000	700	72	20	0.038	0.7	0.038	0.300	10	4	54	55	65	7.44			0.120	0.227	1.0
4	11	9.5	85000	2200	137	0	0.105	1.1	0.007	0.120	6	4	56	63	70	7.54			0.095	0.192	1.0
4	12	7.8	34000	700	111	17	0.045	0.7	0.013	0.090	11	7	54	55	65	7.52			0.110	0.238	1.0
4	13	13.7	34000	400	117	23	0.010	0.4	0.007	0.200	12	6	60	60	70	7.49			0.132	0.405	1.0
4	14	15.9	36000	550	97	53	0.045	0.8	0.010	0.180	11	14	56	60	75	7.57			0.139	0.495	1.5
4	16	5.8	41000	800	106	26	0.020	0.3	0.013	0.400	8	5	44	45	55	7.45			0.074	0.331	1.0
4	17	4.6	39000	850	116	57	0.038	0.3	0.013	0.200	4	5	48	50	55	7.90			0.065	0.555	1.0
4	18	12.4	19000	400	117	90	0.045	0.3	0.013	0.060	6	7	58	53	63	7.75			0.077	0.584	1.0
4	19	9.2	40000	920	119	46	0.015	0.4	0.013	0.340	5	2	56	50	55	7.79			0.065	0.449	1.0
4	20	5.8	30000	700	44	30	0.015	0.6	0.007	0.180	6	2	52	50	70	7.70			0.091	0.484	1.5
4	22	5.3	14000	600	55	12	0.028	0.9	0.013	0.110	7	8	56	45	68	7.70			0.095	0.425	1.5
4	23	7.6	30000	350	50	10	0.052	0.7	0.007	0.190	8	7	52	48	70	7.71			0.093	0.394	1.0
4	24	0.0	15000	150	47	0	0.038	1.1	0.038	0.840	7	5	42	40	55	7.60			0.098	0.248	1.5
4	26	6.6	30000	300	44	5	0.028	1.7	0.013	0.300	12	10	72	65	95	7.60			0.174	0.067	1.5
4	27	11.0	24000	150	32	32	0.020	2.0	0.001	0.200	20	10	100	90	135	7.51			0.249	0.049	1.0
5	1	9.9	12000	1300	147	60	0.030	1.1	0.026	0.100	99	80	200	192	344	7.70			0.764	0.044	1.0
5	2	7.0	15000	670	193	60	0.033	1.2	0.043	0.300	15	9	87	88	116	7.31			0.208	0.227	1.0
5	3	9.2	6500	1200	143	23	0.001	1.4	0.035	0.120	17	22	77	88	118	7.39			0.230	0.071	1.0

STO RM	HR	BOD	TOTAL C OLIFORM	F. COL IFORM	TSS	VSS	AMMC NIA	NIT RATE	NIT RITE	ORTHO PO4	CHLO RIDE	SUL FATE	T. ALK ALINITY	CA. HA RDNESS	T. HA RDNESS	PH	COL OUR	TURBI DITY	S. COND UCTANCE	DISCH ARGE	WEI GHT
5	4	8.7	10000	1200	105	60	0.023	1.4	0.010	0.116	19	18	87	92	136	7.28			0.267	0.060	1.0
5	5	3.6	12000	1300	118	45	0.0	1.3	0.032	0.0	25	20	97	104	152	7.29			0.303	0.022	1.0
5	6	7.6	11000	1600	88	15	0.001	1.4	0.003	0.001	29	22	130	108	170	7.30			0.372	0.005	1.5
6	1	17.3	9000		197	75	0.030	2.3	0.045		139	158	240	245	440	7.50			0.929		
6	3	38.2	6800		363	43	0.340	1.5	0.075		97	80	160	145	255	7.36			0.603		
6	5	62.6	7200		137	0	0.065	1.5	0.125		41	59	108	115	170	7.31			0.355		
6	7	37.1	5500		31	0	0.240	1.3	0.113		45	68	120	125	200	7.21			0.412		
6	9	19.2	9000		46	6	0.030	1.9	0.035		45	58	108	115	173	7.18			0.383		
6	11	18.1	8300		134	9	0.175	1.3	0.075		19	39	68	70	95	7.25			0.190		
6	13	16.8	110000		97	0	0.150	1.2	0.058		23	43	84	80	120	7.30			0.256		
6	15	17.8	11000		154	74	0.200	1.0	0.075		31	49	96	95	140	7.25			0.298		
6	19	11.2	15000		97	43	0.240	1.2	0.050		37	58	120	120	180	7.36			0.374		
6	21	9.0	17000		77	51	0.001	1.5	0.058		53	98	172	145	260	7.52			0.527		
6	23		8800		69	23	0.170	2.0	0.075		69	107	196	180	320	6.95			0.584		
6	25		10000		117	34	0.100	1.6	0.070		73	104	164	160	265	6.89			0.517		
6	27		6000		71	0	0.065	1.9	0.090		63	90	168	135	255	6.91			0.450		
6	29		5800		71	0	0.135	2.1	0.075		61	103	184	140	285	7.00			0.502		
6	31		6000		52	17	0.120	1.9	0.063		109	138	232	150	365	7.20			0.584		
6	33		5500		72	32	0.170	1.9	0.108		71	141	200	120	335	7.11			0.517		
6	35		4800		52	9	0.030	2.0	0.065		73	128	236	105	390	7.35			0.594		
6	37		4800		63	26	0.100	2.3	0.055		81	158	256	100	420	7.17			0.632		
6	39		6000		43	43	0.030	2.0	0.073		85	154	264	120	440	7.41			0.660		
7	3	37.6	4400	650	487	129	0.112	1.2	0.123	1.000	666	121	184	108	300	6.79			1.670	0.343	5.0
7	7	30.9	1800	380	200	120	0.024	0.5	0.108	0.001	448	44	56	88	120	7.09			1.090	0.369	2.0
7	9	27.8	1000	750	154	37	0.032	0.8	0.068	0.001	180	22	40	60	88	7.01			0.486	0.198	2.0
7	11	32.4	1300	730	23	23	0.024	0.8	0.048	0.0	50	22	40	46	56	6.94			0.179	0.055	2.0
7	13	14.6	500	310	127	47	0.0	0.7	0.030	0.0	42	25	52	60	90	7.00			0.190	0.001	2.0
8	2	2.0	750	620	305	40	0.0	1.0	0.096	0.480	94	28	136	70	100	7.82			0.282	0.829	1.5
8	3	11.2	500	350	255	93	0.001	0.7	0.044	0.001	34	20	80	65	95	7.81			0.162	1.247	1.0
8	4	24.5	500	420	178	108	0.0	0.0	0.046	0.001	34	16	60	65	75	7.75			0.146	0.644	1.0
8	5	8.8	1000	240			0.0	0.7	0.060	0.120	32	27	56	70	90	7.60			0.162	0.416	1.0
8	6	14.8	300	230			0.024	0.1	0.058	0.0	34	24	64	65	85	7.54			0.177	0.197	1.0
8	7	28.4	1100	700			0.0	0.5	0.068	0.080	36	44	100	100	145	7.39			0.308	0.103	1.0
8	8	24.0	1100	490			0.0	0.5	0.066	0.072	40	52	108	116	165	7.61			0.362	0.114	1.0
8	9	21.5	1700	590			0.0	1.1	0.044	0.001	76	72	148	130	220	7.43			0.461	0.080	1.0
8	10	15.7	600	400			0.0	1.0	0.068	0.160	78	74	156	150	240	7.64			0.491	0.035	1.0
8	11	19.2	1500	340			0.076	1.5	0.040	0.080	90	89	184	180	280	7.60			0.670	0.010	1.0
8	12	24.6	400	60			0.0	1.6	0.052	0.001	92	98	216	190	300	7.73			0.651	0.003	1.0
8	13	13.2	290	280			0.024	2.0	0.032	0.001	100	108	220	205	335	7.65			0.660	0.001	1.0

STORM	HR	BOD	TOTAL COLIFORM	F. COLIFORM	TSS	VSS	AMMONIA	NITRATE	NITRITE	ORTHO PO4	CHLORIDE	SULFATE	T. ALKALINITY	CA. HARDNESS	T. HARDNESS	PH	COLOUR	TURBIDITY	S. CONDUCTANCE	DISCHARGE	WEIGHT
9	1	2.0	19000	690	204	149	0.180	1.7	0.124	0.001	180	200	113	156	304	7.39	120		0.833		
9	2	10.8	14000	1000	433	131	0.133	1.1	0.116	0.001	72	77	87	104	136	7.19	160		0.435		
9	4	23.7	15000	740	528	344	0.045	0.6	0.056	0.0	34	31	70	76	88	7.41	180		0.205		
9	5	24.3	1100	25	288	276	0.019	0.6	0.076	0.0	34	38	67	65	90	6.92	200		0.211		
9	6	31.5	4100	63	272	272	0.045	1.1	0.088	0.0	42	31	57	76	92	7.11	150		0.244		
9	8	31.2	4600	38	260	260	0.045	1.4	0.086	0.0	56	56	70	84	116	7.13	160		0.316		
9	9	38.3	1200	38	180	180	0.067	1.3	0.060	0.0	80	110	160	96	155	7.42	110		0.603		
9	10	29.7	9100	425	96	16	0.045	1.3	0.072	0.0	94	77	87	108	160	7.28	120		0.480		
9	12	51.0	4600	75	216	137	0.045	0.5	0.028	0.0	122	220	284	272	504	7.34	100		0.102		
9	15	32.5	13000	790	344	32	0.045	1.2	0.116	0.0	70	64	123	112	152	7.53	400		0.421		
9	17	4.1	4300	160	250	23	0.067	1.1	0.136	0.001	78	62	100	92	120	7.72	360		0.390		
9	18	25.8	6900	900	265	48	0.001	1.1	0.108	0.0	80	70	117	100	140	7.21	360		0.443		
9	20	19.4	1400	330	216	0	0.001	1.0	0.120	0.0	62	44	90	90	120	7.19	400		0.365		
9	22	52.6	14000	1100	167	17	0.0	1.2	0.128	0.0	62	56	97	100	132	7.12	360		0.382		
9	24	0.0	2700	380	120	6	0.0	1.4	0.086	0.0	86	68	110	108	156	7.29	240		0.481		
9	25	8.0	4800	540	50	0	0.045	1.1	0.076	0.0	130	66	123	144	188	7.32	220		0.632		
9	26	4.2	2600	250	188	188	0.019	1.5	0.056	0.0	128	83	153	148	232	7.39	180		0.699		
10	1	15.9	4900	840	566	226	0.220	1.1	0.190	0.932	1585	63	272	156	216	7.61	270		2.390	0.036	1.0
10	2	22.2	2800	1400	795	310	0.094	1.2	0.168	0.130	1308	57	268	136	220	7.29	320		2.080	0.125	1.0
10	3	33.0	43000	900	257	114	0.094	1.1	0.140	1.160	615	54	124	104	136	7.39	240		1.180	0.010	2.5
10	6	16.8	10000	1600	234	111	0.070	1.0	0.125	1.160	540	57	124	120	168	7.41	220		1.160	0.002	1.0
11	1	11.3	4100	920	280	130	0.033	1.2	0.122	0.750	100	54	128	108	168	7.11	240	500	0.457	0.267	1.0
11	2	11.7	3600	2200	773	257	0.029	0.6	0.070	0.650	32	25	184	56	96	8.02	440	1200	0.154	0.718	1.0
11	3	6.0	1100	1000	457	157	0.045	0.6	0.063	0.810	24	33	80	72	76	7.41	320	600	0.173	0.841	1.0
11	4	5.4	3800	1600	511	63	0.014	0.6	0.063	0.250	40	28	92	80	92	7.72	400	700	0.196	1.030	2.0
11	6	11.3	4100	1100	720	134	0.013	0.9	0.040	0.325	42	36	96	100	116	7.70	280	360	0.290	0.630	1.0
11	7	9.3	3900	1600	269	74	0.0	1.1	0.050	0.600	60	44	112	100	152	7.72	260	300	0.346	0.015	1.0
11	8	6.0	2600	560	134	91	0.055	1.9	0.025	0.250	94	58	160	172	260	7.62	200	160	0.565	0.010	1.0
11	9	10.1	2500	1000	94	91	0.045	2.5	0.045	0.250	100	70	192	164	296	7.88	180	170	0.632	0.002	1.0
12	1		2100	730	220	128	0.030	1.0	0.068	0.750	83	75	112	110	156	7.30	210	280	0.298	0.054	1.5
12	2		300	110	188	153	0.052	0.5	0.070	0.350	83	64	72	85	116	7.20	200	250	0.275	0.046	1.0
12	3		3700	1800	160	100	0.018	0.6	0.052	0.250	85	57	80	80	120	7.51	180	220	0.279	0.040	1.0
12	4		300	120	195	128	0.010	0.6	0.044	0.175	68	30	72	75	92	7.65	200	250	0.218	0.072	1.5
12	6		1400	450	290	143	0.004	0.7	0.040	0.001	33	25	64	60	80	7.60	200	300	0.151	1.598	1.5
12	7		200	180	425	180	0.004	0.3	0.020	0.100	18	33	56	55	68	7.65	200	400	0.095	2.899	1.0
12	8		400	170	226	226	0.004	0.8	0.046	0.175	35	38	88	107	120	7.45	200	260	0.182	1.411	1.0
12	9		300	200	230	173	0.0	0.9	0.048	0.175	35	28	84	75	108	7.59	180	250	0.191	1.099	1.0
12	10		1400	640	185	90	0.0	0.8	0.024	0.250	48	40	96	95	132	7.49	160	190	0.237	0.676	1.5
12	12		500	150	148	98	0.018	1.3	0.020	0.325	63	57	128	135	192	7.62	110	120	0.318	0.444	1.5

STORM	HR	BOD	TOTAL COLIFORM	F. COLIFORM	TSS	VSS	AMMONIA	NITRATE	NITRITE	ORTHO PO4	CHLORIDE	SULFATE	T. ALKALINITY	CA. HARDNESS	T. HARDNESS	PH	COLOUR	TURBIDITY	S. CONDUCTANCE	DISCHARGE	WEIGHT
12	13		500	290	33	33	0.001	1.8	0.044	0.100	80	84	152	170	240	7.56	100	90	0.404	0.274	1.0
12	14		800	180	78	68	0.0	2.1	0.024	0.001	83	84	168	175	260	7.65	100	85	0.459	0.091	1.0
12	15		600	110	68	62	0.036	2.5	0.014	0.100	100	94	196	180	308	7.78	70	50	0.545	0.031	1.0
12	16		3700	1000	24	22	0.010	2.7	0.020	0.400	110	104	216	200	420	7.80	60	55	0.593	0.018	1.0
12	17		1000	180	60	58	0.020	2.9	0.018	0.250	113	102	212	195	424	7.79	80	80	0.612	0.009	1.5
12	19		1300	150	58	42	0.025	3.2	0.020	0.100	125	109	228	190	372	7.90	60	55	0.660	0.008	2.0
12	21		200	40	32	32	0.0	3.1	0.008	0.350	137	136	260	240	415	7.89	40	25	0.746	0.008	1.5
12	22		1000	70	6	6	0.0	3.4	0.010	0.175	140	130	260	260	420	7.82	35	20	0.737	0.008	1.0
12	23		7700	2000	2	2	0.0	3.3	0.004	0.001	138	115	264	270	420	7.88	40	15	0.718	0.008	2.0
12	26		600	80	32	32	0.020	3.4	0.001	0.100	145	115	260	265	425	7.91	30	7	0.767	0.008	1.5
12	27		400	60	1	1	0.004	3.3	0.014	0.001	143	104	264	275	435	7.71	40	10	0.766	0.008	2.0
12	29		400	40	9	9	0.020	3.4	0.004	0.175	143	104	264	260	435	7.87	35	7	0.746	0.008	2.0
12	31		100	10	1	1	0.028	3.3	0.010	0.0	143	145	256	245	430	7.90	35	10	0.756	0.008	2.0
12	33		100	20	2	2	0.004	3.1	0.020	0.175	140	115	256	250	425	7.82	30	15	0.761	0.008	2.0
13	1	12.7	13000	11000	280	83	0.072	1.4	0.040	0.950	145	72	147	140	193	7.52	190	360	0.670	0.118	1.0
13	3	21.4	1800	370	292	165	0.054	0.6	0.060	0.790	56	29	76	52	80	7.61	200	450	0.260	0.350	2.5
13	5	12.3	1700	200	167	83	0.0	0.8	0.065	0.650	40	29	65	50	65	7.58	180	220	0.208	0.289	1.5
13	6	16.5	840	40	146	94	0.026	0.9	0.080	0.800	40	33	64	56	76	7.69	160	180	0.208	0.120	1.0
13	7	13.3	1400	120	117	86	0.010	0.8	0.060	0.510	46	33	76	60	84	7.62	110	150	0.254	0.026	1.5
13	9	20.8	1600	180	63	63	0.004	1.1	0.055	0.300	70	40	104	96	152	7.62	75	140	0.384	0.002	1.5
14	1	23.4	1000	210	240	230	0.033	0.9	0.031	0.100	305	178	240	240	436	7.79	45	160	0.976	0.001	1.0
14	2	7.0	1600	170	80	70	0.059	2.4	0.023	0.200	164	156	292	256	484	7.83	25	30	0.928	0.002	1.0
14	3	2.1	570	190	33	33	0.020	2.3	0.020	1.740	158	136	268	216	444	7.70	30	30	0.919	0.002	1.0
14	4	11.9	790	70	780	317	0.176	0.9	0.065	0.400	86	52	260	116	200	7.45	120	900	0.457	1.820	1.0
14	5	20.4	710	10	420	300	0.0	0.8	0.020	0.580	42	23	220	72	100	7.72	160	1000	0.193	0.170	1.0
14	6	12.0	710	30	476	160	0.001	2.0	0.031	0.440	44	30	148	100	120	7.70	140	700	0.239	0.024	1.5
14	8	10.9	1200	60	180	130	0.0	1.3	0.029	0.600	60	45	180	116	164	7.62	110	370	0.346	0.011	2.5
14	10	3.5	1600	40	113	83	0.0	1.5	0.010	2.500	78	57	156	136	224	7.32	80	220	0.574	0.010	1.5
15	1	12.0	9100	820	233	207	0.115	2.4	0.130	0.520	186	112	244	228	412	7.35	80	240	0.852	0.091	1.5
15	3	14.3	4900	1200	407	163	0.085	1.4	0.145	0.600	44	25	148	80	116	7.50	120	550	0.256	0.370	1.5
15	4	17.3	2100	340	210	117	0.050	1.1	0.065	0.450	44	1	88	88	100	7.58	100	340	0.249	0.329	1.0
15	5	10.2	2200	360	463	153	0.060	2.1	0.095	1.400	45	1	104	80	92	7.41	100	450	0.230	0.289	1.5
15	7	9.9	1000	390	163	83	0.001	2.0	0.035	0.550	50	1	92	88	112	7.15	90	230	0.255	0.078	1.5
16	1	38.4	4600	40	1230	283	0.121	1.7	0.113	0.700	104	47	344	132	220	7.39	140	1100	0.462	0.525	1.0
16	2	33.3	570	60	900	320	0.123	1.3	0.070	0.390	46	29	164	88	120	7.49	150	1000	0.268	0.086	1.0
16	3	23.3	290	120	407	210	0.136	1.5	0.090	0.740	56	43	108	96	124	7.58	140	800	0.301	0.003	1.0
16	4	23.7	790	170	403	143	0.103	1.5	0.078	0.480	60	38	112	112	144	7.36	120	500	0.351	0.001	1.0
17	1	28.6	5300	4700	210	167	0.058	0.5	0.056	0.700	106	89	160	172	276	7.40	140	150	0.622	0.027	1.0
17	2	49.1	6100	1900	197	133	0.025	0.5	0.062	0.420	104	63	136	148	248	7.20	140	200	0.560	0.038	1.0

STORM	HR	BOD	TOTAL COLIFORM	F. COLIFORM	TSS	VSS	AMMONIA	NITRATE	NITRITE	ORTHO PO4	CHLORIDE	SULFATE	T. ALKALINITY	CA. HARDNESS	T. HARDNESS	PH	COLOUR	TURBIDITY	SP. CONDUCTANCE	DISCHARGE	WEIGHT
17	3	24.9	6700	2200	240	110	0.038	0.5	0.094	0.240	62	43	96	96	140	7.49	180	280	0.323	0.014	1.0
17	4	19.7	5900	130	230	140	0.0	0.6	0.032	0.790	50	40	88	92	120	7.40	160	220	0.289	0.008	1.0
17	5	19.9	5300	200	237	120	0.025	0.8	0.072	1.020	74	35	96	95	124	7.37	180	250	0.362	0.011	1.0
17	6	30.9	10300	150	197	97	0.0	0.8	0.062	0.600	70	43	96	100	136	7.29	160	240	0.376	0.025	1.0
17	7	31.0	3700	1300	197	120	0.145	1.1	0.094	0.050	70	43	92	112	148	7.43	140	200	0.371	0.018	1.0
17	8	13.5	6700	5700	253	110	0.0	1.5	0.058	0.700	76	43	92	120	148	7.40	140	220	0.374	0.008	1.0
17	9	29.1	2200	30	183	120	0.0	1.4	0.062	0.900	70	40	92	112	156	7.22	160	180	0.394	0.001	2.0
18	1	42.4	4200	300	920	250	0.0	0.4	0.040	1.000	32	30	156	104	128	7.61	120	800	0.221	1.336	1.0
18	2	7.6	5800	390	553	157	0.0	0.3	0.044	1.300	40	25	76	60	76	7.80	180	550	0.234	0.410	1.0
18	3	2.9	2300	310	292	128	0.0	0.4	0.026	0.040	30	28	80	80	100	7.72	170	350	0.219	0.028	1.0
18	4	3.3	3400	240	337	143	0.0	0.6	0.040	1.190	28	33	84	76	100	7.48	200	330	0.222	0.015	1.0
18	5	2.4		590	250	110	0.0	0.7	0.048	2.100	34	23	88	72	100	7.45	160	210	0.239	0.002	1.0
19	1	12.0	26000	490	143	137	0.144	2.4	0.096	0.140	66	70	112	128	172	7.30	160	190	0.431	0.148	1.0
19	3	11.3	31000	1600	140	126	0.073	2.7	0.104	0.170	27	38	72	76	92	7.50	150	280	0.206	0.349	1.5
19	4	15.8	35000	3400	411	243	0.018	1.4	0.086	0.100	30	26	90	84	100	7.53	200	360	0.213	0.067	1.0
19	6	18.5	40000	4600	291	151	0.021	1.7	0.088	0.540	12	23	86	76	96	7.32	140	360	0.222	0.089	1.5
19	8	13.8	17000	2100	226	154	0.018	2.0	0.082	0.100	42	28	88	90	116	7.47	140	290	0.257	0.011	2.5
20	1	11.5	44000	4300	623	200	0.125	0.9	0.055	0.740	22	20	148	70	80	7.19	200	400	0.181	1.273	1.0
20	2	22.0	11000	11000	697	213	0.078	1.1	0.075	1.900	29	23	208	76	96	7.04	210	650	0.203	0.446	1.0
20	3	46.0	26000	11000	600	227	0.0	1.2	0.073	0.740	40	35	135	95	115	7.01	190	550	0.289	0.059	1.0
20	4	18.0	20000	9400	377	160	0.0	1.5	0.070	0.800	44	33	116	104	156	6.90	180	350	0.325	0.012	1.0
21	1	35.8	22000	11000	1160	287	0.167	1.3	0.080	0.480	25	25	160	96	108	7.50	160	750	0.211	0.849	1.5
21	3	13.0	18000	12000	416	176	0.0	1.5	0.070	0.860	20	28	56	64	72	7.58	170	500	0.158	0.658	1.5
21	4	33.3	13000	7400	1097	293	0.080	0.8	0.070	0.350	17	16	96	70	94	7.52	120	550	0.163	1.019	1.0
21	5	23.5	22000	12000	1052	392	0.133	0.5	0.100	0.720	16	33	122	78	94	7.29	120	600	0.169	0.931	1.0
21	6	22.3	23000	10000	540	195	0.0	0.5	0.024	0.310	13	23	78	80	88	7.38	120	340	0.151	0.133	1.5
21	8	12.8	31000	6500	423	217	0.0	0.2	0.034	0.800	17	28	72	72	82	7.52	100	310	0.183	0.015	2.5
21	10	12.0	33000	3900	370	153	0.001	0.7	0.020	0.720	30	39	94	92	116	7.11	70	170	0.264	0.012	2.0
21	12	9.8	38000	5700	350	180	0.0	0.6	0.014	0.920	38	38	104	106	140	7.40	80	190	0.314	0.108	2.0
22	1	16.8	270000	26000	163	47	0.0	2.6	0.166	0.580	110	96	236	222	338	7.52	90	120	0.833	0.013	1.0
22	2	38.5	44000	9900	190	63	0.075	2.7	0.162	2.100	48	51	108	126	160	7.38	180	210	0.450	0.078	1.0
22	3	78.4	48000	1200	337	103	0.0	4.4	0.208	0.960	36	51	128	120	158	7.38	200	390	0.382	0.133	1.0
22	4	23.8	71000	8500	133	43	0.0	4.7	0.220	0.760	38	57	90	118	148	7.40	160	140	0.380	0.065	1.0
23	1	70.8	300000	34000	743	363	0.244	1.4	0.570	0.440	80	73	148	148	218	7.10	140	500	0.550	0.193	1.0
23	2	18.5	920000	170000	270	206	0.110	2.5	0.172	1.410	20	38	72	88	98	7.36	140	180	0.218	0.540	1.0
23	3	23.8	200000	17000	610	287	0.045	1.2	0.128	0.520	17	28	94	86	92	7.12	80	380	0.190	0.576	1.0
23	4	34.5	170000	29000	520	328	0.029	1.3	0.050	0.720	19	24	86	90	128	7.24	120	380	0.200	0.270	1.5
23	6	17.5	130000	22000	364	252	0.088	1.5	0.078	0.710	23	37	84	55	110	7.21	90	240	0.241	0.249	1.5
23	7	45.5	170000		544	296	0.097	0.4	0.013	0.560	18	30	93	100	105	7.25	90	450	0.217	0.231	1.0

STORM	HR	BOD	TOTAL COLIFORM	F. COLIFORM	TSS	VSS	AMMONIA	NITRATE	NITRITE	ORTHO PO4	CHLORIDE	SULFATE	T. ALKALINITY	CA. HARDNESS	T. HARDNESS	PH	COLOUR	TURBIDITY	S. CONDUCTANCE	DISCHARGE	WEIGHT
23	8	40.7	110000		300	167	0.053	0.7	0.020	0.800	18	29	82	75	90	7.28	80	290	0.193	0.060	1.0
23	9	46.7	120000		340	213	0.080	0.6	0.006	0.520	29	37	104	100	132	7.12	60	180	0.279	0.030	1.5
23	11	36.0	130000		333	240	0.070	1.1	0.028	0.360	40	38	116	112	144	7.31	70	170	0.343	0.005	1.5
24	1	15.0	98000	4300	571	74	0.048	0.8	0.034	0.670	6	12	84	56	68	7.71	80	340	0.131	2.895	1.0
24	2	18.2	120000	1300	554	103	0.025	0.4	0.040	0.650	7	17	76	72	88	7.39	70	270	0.168	1.160	1.0
24	3	40.5	110000	1900	928	143	0.008	0.7	0.040	0.980	9	19	88	72	96	7.42	70	460	0.182	0.060	1.0
24	4	27.5	130000	2000	817	126	0.010	1.1	0.030	1.000	12	24	102	90	124	7.12	70	385	0.250	0.015	2.0
25	2	27.7	1200000	200000			0.140	3.1	0.200	0.810	119	119	284	260	434	7.33	45	201	0.947	0.060	2.0
25	3	18.5	1000000	140000			0.118	3.0	0.228	0.880	122	117	302	256	440	7.42	45	207	0.966	0.083	1.0
25	4	14.0	800000	110000			0.126	3.4	0.158	1.200	128	131	293	255	495	7.55	50	270	1.015	0.216	1.0
25	5	30.0	860000	90000			0.053	0.8	0.134	0.400	20	31	108	78	98	7.38	100	360	0.220	0.289	1.5
25	7	25.7	610000	90000			0.015	0.9	0.021	0.490	10	26	76	68	90	7.40	80	470	0.161	0.759	1.5
25	8	29.2	190000	11000			0.006	0.6	0.023	0.560	10	18	75	80	83	7.28	70	325	0.134	0.411	1.0
25	9	19.7	400000	33000			0.0	0.2	0.018	0.260	9	26	88	72	96	7.27	60	220	0.200	0.182	1.0
25	10	46.5	110000	5800			0.0	0.9	0.040	1.060	17	14	85	0	113	7.21	90	255	0.215	0.262	1.0
25	11	19.0	510000	38000			0.028	0.5	0.016	0.540	7	16	80	69	82	7.17	150	335	0.154	0.310	1.0
25	12	26.0	180000	9300			0.028	0.9	0.016	0.360	7	14	80	70	85	7.32	140	265	0.164	0.152	1.0
25	13	28.0	320000	27000			0.001	0.5	0.015	0.360	9	29	88	80	108	7.22	120	280	0.201	0.042	1.0
25	14	26.5	130000	13000			0.010	1.2	0.023	0.300	10	26	104	84	115	7.32	100	400	0.219	0.018	1.0

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VITA AUCTORIS

Ronald Lawrence Droste was born on April 9, 1946 in Clinton, Iowa, U.S.A. He graduated from Clinton High School in June, 1964 and entered the University of Notre Dame, Notre Dame, Indiana, graduating in June, 1968 with a Bachelor of Science degree in Engineering Science.

He was accepted in the Faculty of Graduate Studies, University of Windsor in September 1972 leading to the degree of Master of Applied Science in Civil Engineering.